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BREEDING AND IMPROVEMENT OF FARM ANIMALS

BY

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First Edition

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TO
JOHN CHESTER McNUTT
FRIEND AND TEACHER

PREFACE

This book has been written primarily for use as a textbook of animal breeding. It treats the subject of breeding practice from the scientific standpoint in so far as this is possible at the present time. Breeding is an art to be learned only by practice, but knowledge of principles supplies the only firm foundation for its practice. Superior animals will be more numerous when breeders know why as well as how.

The practice of breeding antedates by many centuries any attempt to understand its natural underlying laws. The facts of practice furnish the working materials of science. These relationships should be thoroughly understood and constantly kept in mind. Without definite knowledge of principles a high degree of excellence in the production of beautiful and efficient animals has been attained. In the field of animal breeding the contribution of science has been largely explanatory thus far. Time only can prove what further functions it may fulfill.

I wish to express my thanks to the Editors of The National Geographic Magazine for permission to use the quotation from The Taurine World, facing the first page and to the many other authors and publishers who have kindly granted permission to quote or to use illustrations from their works.

I am deeply appreciative of the assistance which many friends have rendered in the preparation of this book. My especial thanks are due Miss M. R. Burr, for her suggestions and help in reading the proofs. I take pleasure in acknowledging my very great indebtedness to the late editor of this series, Dr. Charles V. Piper, for his friendly counsel and his constructive criticisms.

V. A. Rice.

Amherst, Mass.
August, 1926.

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An artist, modeling in plastic clay or conjuring with marble, brings forth a conception that the world acclaims a triumph. He deals, however, with his materials direct, and they respond instantly to his slightest touch, as he toils toward a preconceived ideal. There is no resistance to his manipulations.

What, then, should be our estimate of the work of one who has first to conceive the figure in his brain; whose only tools are the laws of heredity, selection, inbreeding, outcrossing, and alimentation; whose only materials are flesh and blood, unapproachable except by indirection; who battles ever against the stubborn forces of atavism or reversion to ancestral forms; who seeks, and succeeds in producing, a creature pulsating with life, exquisitely fashioned, down to the minutest detail, not only a thing of beauty in itself—which artists try, sometimes with ill success, to reproduce on canvas or in bronze—but a creation that serves as well the highest utilitarian purpose?

The breeder of animals (or plants) directs the spark of life itself. The possibilities of his art are almost infinite.—A. H. Sanders.

The National Geographic Magazine,
December, 1925.

THE BREEDING AND IMPROVEMENT OF FARM ANIMALS

CHAPTER I

INTRODUCTION

Just when the domestication of animals began is unknown; it certainly was long before there was any thought of, or means for, recording historical data. Domestication very likely began late in the Old Stone Age and received decided impetus during the New Stone Age. Each domestic animal has had a rather restricted and humble origin, yet through constant selection for one or another character all of the multifarious forms have evolved—some useful, some ornamental, some having both qualities and some neither. Selection always has been and will always be the key to animal breeding. Although the exact beginning of the domestication of animals is unknown it seems logical to infer that, with the possible exception of the dog, it arose when man ceased to be a hunter and a roamer and adopted a more or less settled mode of living. This new mode of living demanded that food be close at hand. This in turn necessitated

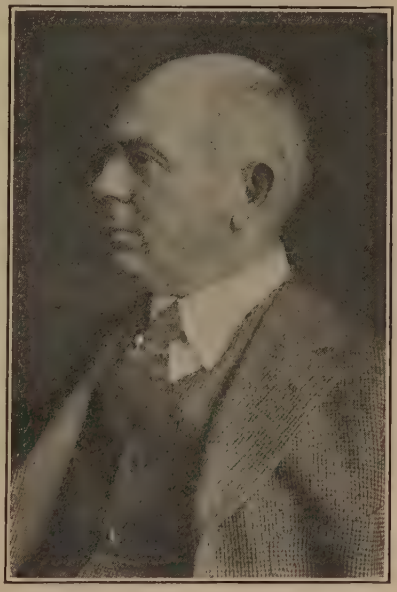


FIG. 1.—W. W. Marsh, Waterloo, Iowa. Guernsey breeder and the first American to be honored with the title Master Breeder. (*Photo. Courtesy Breeders Gazette.*)

plant and animal culture. From that remote time to the present, man has been growing plants and animals, selecting promising variations, and eventually establishing pure strains of plants and pure breeds of animals. Plants, and more especially animals, have reached a stage of marked efficiency through long periods of breeding. Superior animals were no doubt developed by each of the ancient civilizations and suffered retrogression with the decline of the civilization of which such development was a product.

FIG. 2.—St. Bernard (Ch. blueboy 203 lb.) and Mexican Chihuahua (Rosemary 2 lb.), results of natures variation and mans selection. (*Underwood and Underwood.*)

The Dog.—The indications are that the dog was the animal first domesticated. There are now recognized six distinct types of dogs, namely; the Wolf-like group, the Greyhound group, the Spaniel group, the Hound group, the Mastiff group, and the Terrier group. All types have come from two remote ancestors,

the wolf and the jackal, in something like 7,000 years. All of them, from the huge Newfoundland to the tiny Pekinese, are the result of *nature's variations* and *man's selection.*

The Horse.—It seems probable that the horse was the last animal domesticated by man and that the horse has also come from at least two original stocks. One, represented by the Sewalik horse, was a tall, slender-limbed species with broad forehead and tapering face. The other, represented by the Mongolian horse (Przevalski), was a shorter, stouter-limbed, more rugged

FIG. 3.—The "Tarpan," a Mongolian wild horse from which the horses of Western Europe have been derived. (*Photo. from The Outline of Science.*)

type. Evidence seems to point to the fact that horses at one time were a source of meat and milk for certain peoples. It is possible that this was their first service to man, followed later by that of pack and draft, and still later that of riding. The development of the Arabian horse by the Bedouins of the desert is generally recognized as the first great achievement in animal breeding of which there is any definite record. Because the Bedouins' safety often hinged upon the speed and endurance of their horses, these people surrounded their breeding operations with an air of superstition and mystery, much of which has persisted in certain quarters to the present day. The Arabian

breed was used later to refine the large "cold-blooded" horses of the countries to the west and north, particularly of France and England. The Arabians, at a still later date, were used to cross with the race horse of England, thus laying the foundation for the Thoroughbred.

Cattle.—In cattle, the Celtic Shorthorn, found only under domestication, was the only domesticated ox in the British Isles until 500 A. D. when the Anglo-Saxons came bringing with them the great ox, or Aurochs, of Europe. These two stocks furnish the originals from which have come many of the breeds of cattle found in America today.

FIG. 4.—West Highland cows, of great antiquity and indigenous to Great Britain. (*Photo. from The Outline of Science.*)

The cattle of India and Africa are mostly a very different species. These animals have been derived largely "from the India humped cattle, which, in turn, are descended from the Wild Malayan Bantin." Most of these breeds carry a fleshy lump on the withers which weighs upwards of 40 pounds. The zebu, a humped species, has been imported into the southwestern part of the United States for the purpose of crossing on the native cattle, the zebu being highly resistant to tick fever.

The India buffalo of Arna is used for draft as well as meat and milk purposes by the natives of India, Ceylon, and the Malay States, while the Yak (nearest living relative of the Bison), found in Tibet and imported into Siberia is used for the purposes of draft, riding, food, and clothing.

Sheep and Goats.—The sheep, most important of wool-bearing animals, was originally, as some breeds are still, a hairy animal with an under fur of wool. No doubt, people in cold climates who used skins as clothing were the first to begin the selection of sheep for wool production. As in all our domesticated animals, there is wide variation among sheep; some, as the African long-legged and the Abyssinian maned sheep, bear hair instead of wool, some have spiral horns two or more feet in length, others no horns at all. The tail of the common, domes-

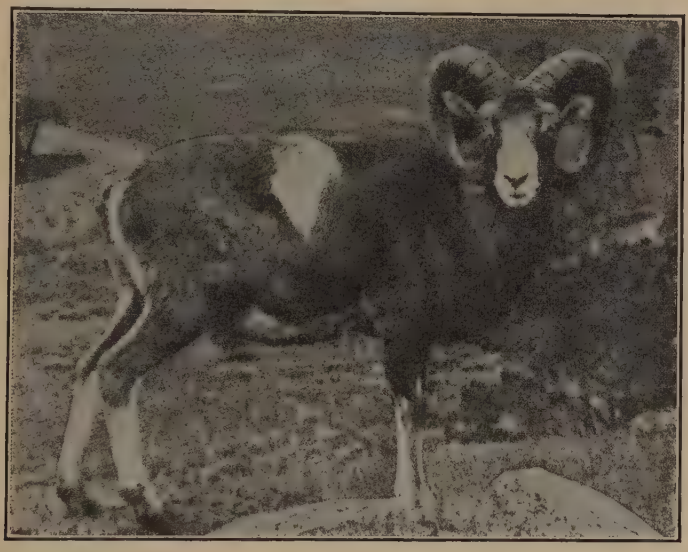


FIG. 5.—The Mouflon—a wild sheep lacking uniform color and having an exterior coat of hair. (*Photo. from Coffey, Productive Sheep Husbandry, J. B. Lippincott Co.*)

ticated sheep is long and slender; in some other strains it is loaded with fat and a foot in width, while still others have merely a vestige of a tail. The latter sort often carry huge patches of fat on the rear quarters, the stored fat in all cases serving to tide the animal over periods of food shortage. The Hunia, a tall, long-legged sheep is used for draft purposes and another, the Barwal sheep, is used in India as a fighting sheep, being pitted against its fellows or other animals.

Goats, close relatives of the sheep, are also versatile in characteristics, yielding the under fur for Kashmir shawls, as well as Mohair, milk, meat, draft power, and also providing one means of clearing up brush land.

Swine.—Swine, probably domesticated later than cattle or sheep, have come from two distinct stocks. One of these was the wild boar, from which have come the breeds of northern Europe, while the other was the Malayan pig, the ancestor of the breeds of southern Europe, Asia, and Africa. The former was a larger, coarser, animal throughout than the latter. Present-day breeds are probably a blend of these two. Selected for ability to fatten rapidly and economically, the pig is foremost in converting feed into flesh and is second to none in the economy of American meat production.

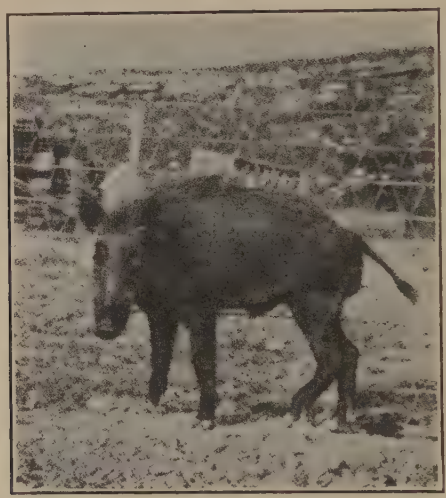


FIG. 6.—A European wild boar, one of the progenitors of modern swine. (*Photo. The Journal of Heredity.*)

Modern Purebreds.—The rise of the present-day pure breeds of domestic livestock dates back a comparatively short time. Practically all of them arose during the eighteenth and nineteenth centuries. A few breeders saw the desirability of intensifying the "blood" of the outstanding individuals when they appeared, and dared, in the face of popular fear and disapproval, to inbreed to achieve their ends. Their methods proved efficacious, though it is quite certain that these old breeders could have advanced no scientific explanation for the results obtained. In terms of genetics they were taking a very heterozygous strain, inbreeding it, thus sorting it out into homozygous form, and then disposing of those undesirable animals which were no doubt carrying a

double set of recessive factors. Such methods are still efficacious and it is a question as to whether they are being used as much as they might well be used today.

Breeding Opportunities.—Although it cannot be denied that well-nigh perfect specimens of the various classes and breeds of livestock have been produced, and while it is true that in practically all breeds the prices paid for individuals have risen well into the thousands of dollars, the fact remains that opportunity is still written large before animal breeders. A few nearly perfect specimens have been produced and record after record has been established only in a short while to be replaced by a better one. The record in milk production during 1 year is 37,381 pounds; in butterfat, 1,614 pounds; in speed at the trot for 1 mile, 1:56¾ seconds; at the pace, 1:55¼ seconds; in the development of power by a team of horses, 21.2 horsepower. Recently there was reported a hog that when killed dressed out 1,145 pounds and the record in the ton-litter contest stands at 4,789 pounds, the combined weight attained by a litter of 16 pigs in 180 days. These records are far above the average and show the heights to which a well-bred and well-fed animal can reach.

FIG. 7.—Successive stages in the development of the horse from a small 4 or 5 toed animal. (*Photo. Courtesy F. B. Loomis, Amherst College.*)

Some Statistical Data.—Table I has been adapted from the U. S. Department of Agriculture preliminary figures for 1924. There are two interesting points brought out by it, namely, the magnitude of the total value of livestock in the United States and the meagerness of the average value of these animals. Both of these points indicate opportunity for the livestock breeder.

TABLE I.—NUMBER AND VALUE OF FARM ANIMALS—UNITED STATES, 1924

	Number	Farm value, per head	Total value
Horses	18,263,000	$64.41	$1,176,282,000
Mules	5,436,000	84.20	457,697,000
Milk cows	24,675,000	52.16	1,287,044,000
Other cattle	42,126,000	24.99	1,052,599,000
Sheep	38,361,000	7.88	302,092,000
Swine	65,501,000	9.75	638,793,000
Total	194,362,000	.....	$4,914,507,000

A compilation by the Bureau of Crop Estimates shows that: "Of every $100 worth of products sold by all who reported (10,000), approximately $36 were for live animals, $20 were for the products of livestock, $40 were for crops, and $4 represented miscellaneous items." Though not all-inclusive, the report states "complete returns from all farmers probably would not materially modify these figures."

Average Value of Animals.—The modest value of the average horse, cow, sheep, or pig should provoke serious thought on the part of the country at large. The average horse is listed as worth $65; milk cow, $52; sheep, $8; and the hog, $10. These average values indicate that billions of dollars worth of materials are being produced yearly in the United States with low-grade, inefficient animals. Such economic waste should be checked as soon as possible.

The U. S. Department of Agriculture is sponsor for the statement that the present low average yield of milk (4,000 pounds) and of fat (160 pounds) by our dairy cows is largely due to the fact that 75 per cent of the dairy bulls in use in the United States are either grades or scrubs. This Department also states that only 3 per cent of our dairy cattle are purebred, and that only

about 2 to 3 per cent of the swine in the United States are purebred and registered.

Purebred Values.—Table II indicates prices of purebreds for the year 1921:

TABLE II.—AVERAGE PRICES OF PUREBRED LIVESTOCK (*From Field Year Book* 1921)

Breed			Average
Cattle:			
Aberdeen-Angus	1921	2,232 head	$272.39
Hereford	1921	6,992 head	202.00
Polled Hereford	1921	820 head	217.85
Red Polled	1921	59 bulls	126.73
		157 females	133.32
Shorthorn	1921	4,761 head	310.69
Polled Shorthorn	1921	Approximately per head	200.00
Ayrshire	1921	At 5 sales 225 head	287.70
Guernsey	1921	At 34 sales 1,621 head	345.52
Holstein	1921	12,961 animals	274.98
Jersey (*Jersey Bulletin*)	1921	3,050 animals	296.31
Horses:			
Shire	1921	Stallions, $600–$1,000	
	1921	Mares, $400–$500	
Suffolk	1921	Stallions, $600–$1,000	
		Mares, $300–$600	
Sheep:			
Cotswold	1921	Rams, $30; ewes, $25	
Swine:			
Chester White	1921	Bred females: range $50–$1,600	75
		Open females: range to $275	50
Duroc-Jersey	1921	$75–$100, with many sales at lower figures	
Hampshire	1921	Selling price bred sows and gilts January to March	117.50
		Same September to November	50
		Mail-order sales during July, August, and September, $85	

The value of purebred animals is forcibly brought out by the above compilation of extensive data secured from most of the

breed associations in America. There can be no question but that the average purebred animal is a more efficient and more valuable animal than the average grade animal, though like all other rules this one has its exceptions. The necessary first step toward raising the average level of excellence in flocks and herds was recognized and taken by the U. S. Department of Agriculture a few years ago in "The Purebred Sire Campaign." A measure of the effectiveness of this campaign will be available in a few years in the form of average values and average production in the various classes of livestock.

Foods of Animal Origin.—A rapidly increasing population does not necessarily mean the extinction of any particular class of livestock. It should however mean the rapid passing of inefficient members of all classes. Thickly populated European countries still produce meat, milk, wool, and power and while actual numbers of animals may be decreasing in the United States from the peak of 1900 yet increasing meat and milk consumption is possible because of increasing yields per animal in dairy cattle and earlier maturity in meat animals. The population of the United States was about five million in 1800 and grew to about ninety-six million in 1910. It has been variously estimated that the total population that can be provided with home-grown food in the United States will be from two-hundred million up to three-hundred and thirty-one million and that this saturation point will be reached in from 75 to 150 years. This is based on maintaining the present dietary standard. It would be possible to maintain a much larger population on primary food products (grains, etc.), because of the unavoidable losses in all animal feeding and the fact that no return is gotten from that portion of the animal's food that goes for maintenance and which amounts to approximately one half. Much energy is stored in a form not suitable for human consumption, however, and there is the added consideration of soil productivity both of which make animal raising indispensable.

The following graph[1] shows the trends of different animals per capita in the United States:

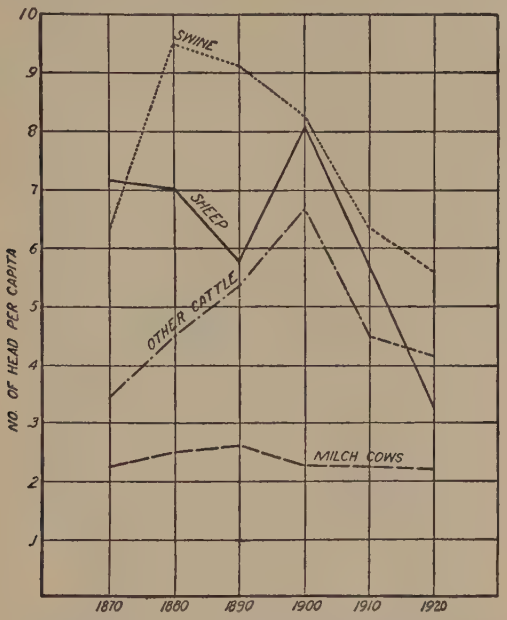


FIG. 8.—Graph showing the number of the different classes of farm animals per capita in the U. S. 1870–1920. (*After East.*)

Figures compiled by Prof. E. N. Wentworth give a picture of the trend toward lower meat consumption. They are:

TABLE III.—MEAT CONSUMPTION PER CAPITA

YEARS	POUNDS
1830 to 1900	182
1900 to 1910	170
1910 to 1920	152
1920 to 1922	138

Such trends as the graph and table above indicate are inevitable. Do they mean the passing of animal foods from our dietary? Probably they do not. Nevertheless they should mean the rapid passing of inefficient animals of which there are a goodly share at present. Meats are palatable and nutritious and will be utilized as long as they can be secured and paid for. At the present time,

[1] EAST, E. M., Mankind at the crossroads, p. 172, Charles Scribner's Sons, 1923.

milk would seem to be an indispensable article of diet and Fig. 8 shows that dairy cattle are practically maintaining their numbers. If they are increasing in average yield of product there is perhaps no less milk being consumed per capita of an increasing population.

Dietary standards, rough feeds, and climatic and soil conditions would seem an effectual barrier against the passing of livestock. Increasing population means an increased demand for food of all kinds, hence, no time should be lost in raising the efficiency of food production to the highest possible level. In

FIG. 9.—Wm. Duthie of Collynie, a Shorthorn breeder who held annual sales for 39 years and sold 1,022 head, mostly bull calves, for a grand total of $1,238,646. (*Photo. Courtesy Breeders, Gazette.*)

such a program there will surely be found a place for all of the really efficient animals that can be produced.

The Equipment of the Breeder.—Breeding is the improvement of animals through rational selection of germplasm and full development of resulting somatoplasm. A cursory glance at the qualifications requisite in one who is to improve animals removes at once any surprise at the scarcity of such breeders. These men, as Bakewell, Cruickshank, Col. Taylor, Lothrop Ames, Gentry, Duthie, Marsh, and a score of others of greater or less

fame are, comparatively speaking, very rare because of the size of the task and the multiplicity of details with which a breeder must deal.

Successful breeders are equipped with keen powers of observation; are thorough students of animal form and function, enabling them to select and mate wisely; are good farmers and intelligent feeders, thus bringing to full expression the inherent potentialities of their animals; and they are not deficient in business acumen which makes possible the accumulation and wise use of capital. They are of the type of men who inspire loyalty and fairness from those with whom they come in contact. In short, successful breeders are usually hard-working, practical idealists who appreciate the privilege of working with the Creator in molding nature's forms more closely after the Ideal.

CHAPTER II

THE PHYSICAL BASIS OF INHERITANCE

The problem concerning the character and behavior of the physical and chemical entities that carry over the characteristics of the species from one generation to the next is one of the most fascinating of all the problems of life. No doubt men have speculated on it throughout the ages, but it has been only in recent times, through the aid of the microscope and carefully planned breeding experiments, that much real progress has been made. The older speculations, some fairly reasonable, others lacking all reasonableness, have created a vast amount of superstition regarding inheritance. These superstitions persist in many quarters at the present time and have given rise to many queer practices and beliefs.

The historical beginning of the cell theory was in the year 1665, when Hooke first noticed the cellular structure of cork. In 1838, two German scientists, Schleiden and Schwann, announced the cell theory for both plants and animals. In its very briefest form the cell doctrine states that all plants and animals are made up of units called cells. In both the plant and the animal kingdoms are found all degrees of complexity from single-celled organisms like bacteria and amœbæ, to highly specialized structures such as plants and farm animals, which consist literally of millions of cells.

The Cell.—A cell is a bit of living protoplasm in which are to be found vacuoles, plastids, a centrosome, and a nucleus, the whole sometimes surrounded by a wall and sometimes naked. The really important part is the content of the cell, the sum total of which is called protoplasm. This includes the nucleus, centrosome, and the remaining portion called the cytoplasm. The body of any multicellular organism is made up of cells (and cell products) which have arisen through cell division from one original cell called a zygote. The zygote is the product of the union of two reproductive cells, namely, an ovum from the female and a spermatozoön from the male. Following the fertilization of an

ovum by a spermatozoön the resulting zygote begins to grow by means of cell division. This one original cell divides into two cells, these two into four, and so on until the complete organism, consisting of millions of cells in the higher animals, is produced. The complex individuals found among the higher animals are composed of a great diversity of kinds of cells which have arisen through specialization. All the organs of an animal body are composed of cells more or less specialized in form and function for definite purposes—lung cells for breathing, brain cells for think-

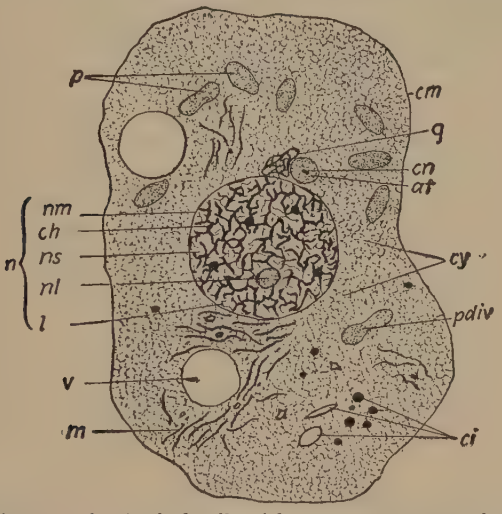


FIG. 10.—Diagram of a typical cell, with structures commonly present. *at*, attraction sphere; *ch*, chromatin net-work; *ci*, cell inclusions; *cm*, cell membrane; *cn*, centrosome; *cy*, cytoplasm; *l*, linin thread; *n*, nucleus; *nl*, nucleolus; *nm*, nuclear membrane; *ns*, nuclear sap; *p*, plastids; *pdiv*, plastid dividing; *v*, vacuole. (*From Principles of Animal Biology; Shull.*)

ing, and so on. Reproduction is likewise affected through the activity of certain specialized cells.

Classification of Cells.—For clarity, and because of certain fundamental differences, the cells making up any organism are grouped into two categories. One of these, called the somatoplasm, includes all the cells necessary to the well-being of the particular individual whose component parts they are. The other relates to the cells immediately concerned in the production of future individuals and is called the germplasm. It is essential that the student differentiate clearly between these two. True, the germ cells are housed in and nourished by the soma or body cells, but differences in cell division as well as in

function place the former in a class by themselves. In farm animals a new individual arises through cell division from a zygote, which is an ovum or egg of the female that has been fertilized by a spermatozoön from the male. Both ova and spermatozoa are cells with the characteristic cytoplasm, centrosome, and nucleus. The ova are produced in the ovaries of the female. Ova are usually larger than spermatozoa because of the stored-up food material in the yolk which must serve to nourish the developing individual until the latter becomes firmly attached in the uterus of the mother. The spermatozoa, produced in the testicles of the male, are also specialized for their function of seeking out and fertilizing the ova. They have a characteristic shape, very unlike that of the ova, being made up of three parts, namely: the head, containing the nucleus; the body, containing the centrosome, and the elongated tail which gives the spermatozoa their motility. The chromosomes found in the nuclei of the germ cells furnish the "bridge of inheritance" between parent and offspring.

Chromosomes.—The theory was advanced many years ago that certain definite entities in the nucleus of the germ cell brought about the development of certain characteristics in the fully developed individual. Subsequent investigation in cytology has proved the correctness of this hypothesis. In the higher animals there is a marked distinction between soma and germplasm, and also between the cytoplasm and the nucleus of the germ cells. It is in the nucleus that the determiners for the individual's characteristics are located. The nucleus itself is made up of two principal parts, the linin network and the chromatin material. This latter goes through various stages in fulfilling its functions. In a resting state, it is strung out in a long thread supported on the linin network. As the cell starts to divide, the chromatin thread shortens and thickens and, finally, breaks up into the number of chromosomes characteristic of the species.

Each species of plant and animal has a characteristic number of chromosomes. This number is also found in most of the cells of the body that have one nucleus, with the exception of the germ cells at certain stages as will be noted later. In the human, the number of chromosomes is 47 in the male and 48 in the female; in cattle, 37 in the male and 38 in the female; in Drosophila, 8; in corn, 20; and in wheat, 16. The chromosomes themselves are divided into two categories, namely: autosomes and sex chromo-

somes, the latter being so named because they carry the determiners for sex as well as for certain other characteristics. The chromosomes occur in a variety of shapes, though for the most part they are rod-like or oval in shape. Abundant cytological and experimental breeding data have now been diligently studied, and it has been proved that each chromosome consists of a great many constituents known as genes or factors.

Genes or Factors.—It is supposed that certain of the filterable viruses which are assumed to be the causative agents in certain diseases, such as hog cholera, are composed quite largely of nuclear or chromatin material with very little or no cytoplasm present. It would seem also that the evolutionary process must have originated in somewhat similar minute bodies and that evolution has consisted of the building up of ever more complex chromatin elements and of grouping them into larger and more complex associations. The most logical reason for the differences between species would seem to be that their chromatin elements differ. During germ-cell division the chromatin becomes stretched out into a long thread and at more or less regular intervals the thread exhibits regions of thickening. In other words, the chromosomes look like a string of beads. These beads are the genes or factors and each gene is supposed to be the determiner (perhaps acting together with other genes) of a characteristic of the adult. Each chromosome is always re-formed from the same group of genes and each gene always occupies a definite locus on its particular chromosome. In Mendelian terminology the genes are, therefore, the unit factors.

Somatic Mitosis.—Somatic mitosis or cell division is the process whereby one cell through growth and subsequent division into equal halves produces two cells. Somatic mitosis is a continuous process starting with one cell in the resting state, and ending with two cells in the resting state. For clarity the process is often divided into four phases, as follows: prophase, metaphase, anaphase, and telophase.

In a typical cell in the resting state, the chromatin of the nucleus is strung out into a long thread and wound in a sort of ball. In the prophase, a shortening and thickening of the chromatin and its division into the number of chromosomes characteristic for the species, together with the arrangement of the chromosomes in an equatorial plane, takes place. The nuclear wall also disappears during this preparatory stage. By this time the centrosome,

which lies just outside the nucleus, has divided, and one half of it has proceeded to each pole of the cell with the accompanying

FIG. 11.—Diagram of mitosis in a four chromosome species, 1–5, prophase; 6–8, metaphase; 9, anaphase; 10, telaphase.

arrangement of the asters attached to the chromosomes. In the metaphase, the chromosomes split lengthwise into two equal parts and these parts start to move to the opposite poles of the

cell. In the anaphase, the two groups of chromosomes complete their migration, one group to each pole of the cell. In the telophase, the cell wall constricts into two new daughter cells, each with cytoplasm, centrosome, and nucleus with its chromatin, in place of the one original parent cell. Such cell division with differentiation is characteristic of the rise of a many-celled organism from a single-celled zygote. At times this process stops short and a dwarf results; at other times it continues beyond the normal, the individual with an extra number of cells being a giant. Various types of abnormalities arise from causes unknown. The force that specifies when, where, and how differentiation is to take place is not known. Perhaps it is the result of response to internal stimuli, perhaps to pressure of other cells, perhaps to something else. Up to the present, it is a mystery, and the wonder should arise, not at the fact that occasionally abnormalities are produced, but, rather, that the whole complicated process from the one to the billions with consequent differentiation is ever accomplished perfectly.

Origin of Germ Cells.—The mode of origin of germ cells is a very important consideration. They are produced in testicles and ovaries but they should be thought of as lineal descendants of the fertilized ovum that has also given rise to the entire somatoplasm of the individual now producing germ cells. At sexual maturity germ cells will begin to be produced by certain specialized portions of this somatoplasm; but the chromosomes and genes in these germ cells are not derived from the body of the parent (somatoplasm) but from the same source from which the body of the parent has come, namely the fertilized ovum or zygote.

Germinal Mitosis in the Male.—The primordial germ cells of the male are found on the inner wall of the seminiferous tubules of the testicles; those of the female just below the surface of the ovaries. At sexual maturity these cells are stimulated to the production of functional spermatazoa and ova. The primary spermatocyte grows and enlarges and then after going through the process of synapsis it divides into two secondary spermatocytes. Synapsis is the stage during which the pairs of homologous chromosomes (one member of each pair having come originally from each parent) conjugate or fuse together. This is diagramed in Fig. 12, and it is a very important stage in the production of germ cells because it offers the opportunity for the interchange of

chromatin material between the pairs of homologous chromosomes, thus providing opportunity for variation. The filaments of

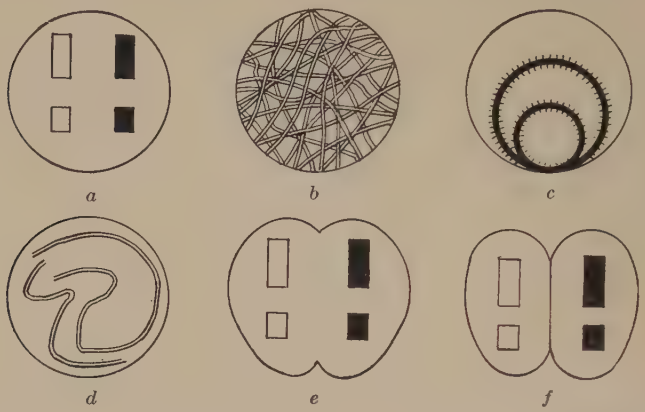


FIG. 12.—Diagram illustrating synapsis and reduction. *a*, primary spermatocyte of a four chromosome species; *b*, preparatory stage; *c*, synapsis, homologous pairs of chromosomes fused; *d*, unravelling of synaptic knot; *e*, chromosomes moving to opposite poles; *f*, the two secondary spermatocytes each with the reduced number of chromosomes.

chromatin twist about each other at this time, and equal sections of chromosomes are no doubt mutually replaced by the other member of the homologous pair. This is what the micro-

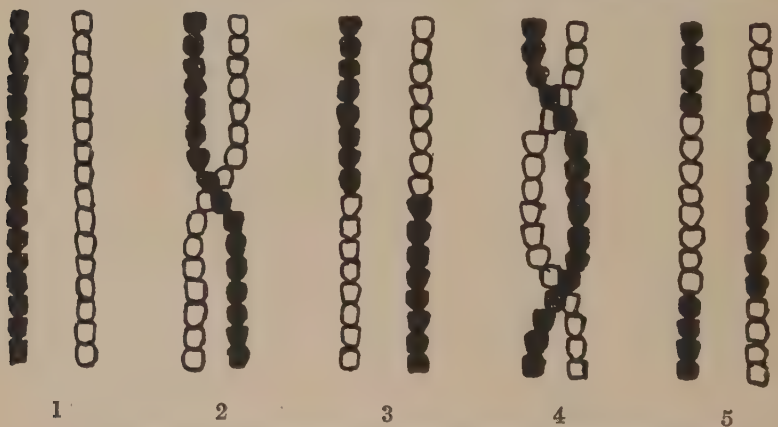


FIG. 13.—Diagramatic representation of single crossing over between homologous chromosomes 1–3; and double crossing over 4 and 5.

scope seems to reveal and it is in keeping with the known way in which characteristics behave in transmission. This interchange is diagramed in Fig. 13.

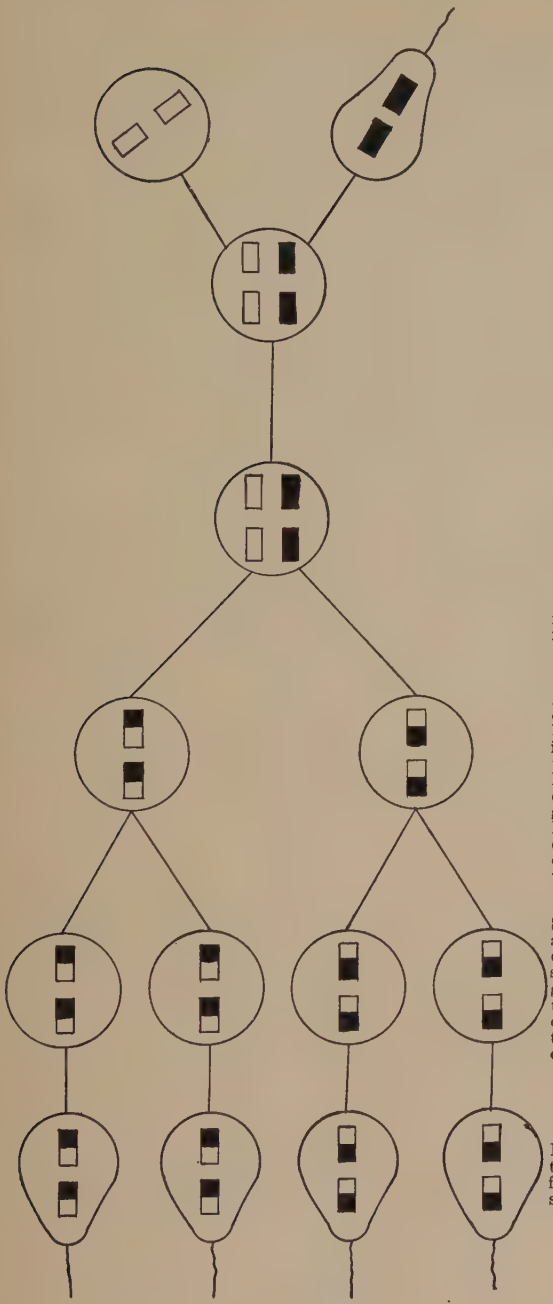

Nucleus of a zygote which will eventually develop into an individual and at maturity produce germ cells.
A primary germ cell (spermatocyte) produced in the tubules of the testicles.
Reduction division including synapsis as diagramed in Fig. 12.
Secondary germ cells with one-half the normal number of chromosomes, showing the effects of chromatin interchange between homologous chromosomes during synapsis, as diagramed in Fig. 13. This is known as the heterotypic division because these two cells are different from the parental cell.
Spermatids, each pair has arisen from the one parent cell by ordinary cell division, as found in somatogenesis. As each of the two daughter cells is exactly like their parent, this is the homotypic division.
Four functional spermatozoa which have arisen from the one primary spermatocyte.

FIG. 14.—Diagram showing germinal mitosis in the male or spermatogenesis.

Such partial interchange of chromatin material, in addition to the independent distribution of whole chromosomes, renders the possibilities of variations infinite, as they seem to be. Synapsis is followed by disjunction of the fused pairs of chromosomes, one member of each pair now moving to one or the other pole of the cell. Upon the completion of this migration of chromosomes the cell wall constricts, forming two secondary spermatocytes each with one-half the number of chromosomes normal for the species. This division is spoken of as the heterotypic division because the two resulting cells are not identical with the parent cell.

The two secondary spermatocytes now divide as in ordinary somatic mitosis, producing four spermatids. As the two cells arising from each secondary spermatocyte are identical with the parent cell, this is spoken of as the homotypic division.

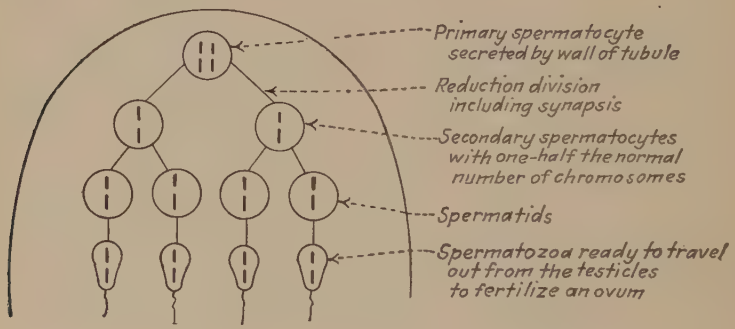

Primary spermatocyte secreted by wall of tubule
Reduction division including synapsis
Secondary spermatocytes with one-half the normal number of chromosomes
Spermatids
Spermatozoa ready to travel out from the testicles to fertilize an ovum

FIG. 15.—Schematic seminiferous tubule showing spermatogenesis.

The four spermatids now develop into functional spermatozoa with characteristic head, body, and tail regions. As cell division proceeds, each generation of cells is becoming further removed from the wall of the tubule and approaching the lumen. The fully developed spermatozoa are found eventually in the lumen of the tubules through which they make their exit from the testicle.

Germinal Mitosis in the Female.—In the ovary of the female, a process identical with that fully described above for the male goes on, with the following exception. Starting with a primary germ cell, or oöcyte, in the ovary the reduction division including synapsis is the same as found in the male, except that in the female, instead of two secondary spermatocytes there is formed

one secondary oöcyte and one non-functional polar body, each of which, however, has received one-half the chromatin material and contains one-half the normal number of chromosomes. The polar body differs from the secondary oöcyte in having received none of the yolk. These two, the secondary oöcyte and the polar body, then divide, the oöcyte giving rise to one ovum or egg and one more polar body, the first polar body giving rise to two polar bodies. The ovum is the female gamete that is capable of being fertilized by a spermatozoön. The three polar bodies are non-functional, and are later absorbed. So, while in the male there are produced four functional spermatozoa from each primary spermatocyte, from the primary oöcyte of the female there arise but one functional ovum, and three non-functional polar bodies.

Purpose of Reduction.—The purpose of the reduction division in the secretion of germ cells, in both the male and the female, is to keep the number of chromosomes for the species constant. When an ovum with one-half the normal number of chromosomes is fertilized by a spermatozoön, also with one-half the normal number of chromosomes, the summation of the two halves restores the normal number of chromosomes in the zygote which is to produce the new individual. No doubt, some cases of sterility in hybrids are due to the fact that the two species that were crossed had different characteristic numbers of chromosomes, and, while fertilization and subsequent development are possible, it is nevertheless impossible for the hybrids to produce functional spermatozoa or ova, because the normal pairing of chromosomes and subsequent cell mechanism is interfered with.

Chromosome Distribution.—So far as known, the distribution of chromosomes in germinal mitosis is at random. This may seem to be a careless procedure but at least it coincides with the results of experimental breeding as will be pointed out later. The solid chromosomes in Fig. 16 represent those contributed by the male, those in outline by the female. Following synapsis and disjunction one member of each pair will proceed to one pole and be found in one cell, the other member of each pair will go to the other pole and be found in the other cell. The fact that one member of a certain pair goes to one cell has no effect on the distribution of the other chromosome pairs; in other words the distribution is independent or random, it being understood that one or the other member of each pair must normally go to each daughter

cell. Figure 16 represents all the possible combinations of the eight chromosomes of Drosophila. As will be pointed out later, random distribution is one of the most potent causes of variation.

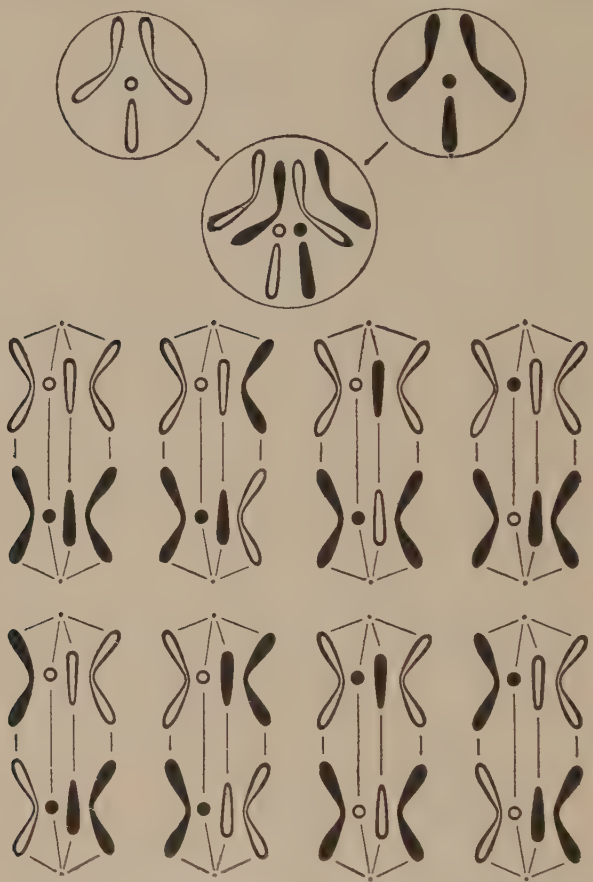


FIG. 16.—Diagram showing consequences of independent segregation of chromosomes in *Drosophila ampelophila*. (*From Genetics in Relation to Agri., Babcock and Clausen.*)

CHAPTER III

THE MALE GENITALIA

The science of physiology seeks to explain the how and the why of all the varied reactions or responses of living organisms to external or internal stimuli; and to determine the function of each organ of the body, as well as the interrelations existing between all parts of the body. The physiology of reproduction seeks to explain the part which each of the specialized organs of this system plays in the animal's ability to reproduce its kind. From the time of the early Greeks on through the dark ages, the works of Galen, an anatomist of the second century A. D., served as the authority in anatomical and physiological science. This was in keeping with the general tendency to believe what someone else had said, rather than to question and to seek to test whether what was asserted was actually true. Galen used the method of observation, but made his observation on animals alone, applying the results in a general way to man. In 1315, an Italian professor, Mondino da Luzzi by name, published a work on human anatomy based on dissection of human bodies rather than on Galen's authority. It remained, however, for Vesalius, a Belgian born in 1514, to break the allegiance to old authority and set up experimental inquiry in its place. After the establishment of the experimental method, in which Harvey, an Englishman, played a leading part, all that remained needful was the perfection of method. Up to the seventeenth century, restricted progress was all that could be expected, for it was not until then that men such as Hooke and Grew of England, Malpighi of Italy, and Swammerdam and Leeuwenhoek of Holland began to develop compound microscopes for the study of minute phenomena of all kinds. Physiology is founded upon the function of organs, but it was not until 1838 that men began to understand even the structure of organs. This development started with the founding of the Cell Doctrine by Schleiden and Schwann in that year.

Preformation and Incasement.—The older thought and belief regarding reproduction was embodied in the "preformation theory." This was, in effect, that the whole body with all its

parts was already contained in the egg of an animal, but in such a minute and transparent form that it could not be detected; that, therefore, the whole of development was nothing more than a growth, or an unfolding, of the parts that were already "infolded." Closely connected with this theory was that of incasement. In this, the ovary of the embryo was supposed to contain the ova of the following generation; these again the ova of the next, and so on *ad infinitum.*

Early Discoveries in Embryology.—Wolff, in 1759, after careful observations, proved that embryonic development did not consist of an unfolding of the performed organs, but was a series of new constructions, one part arising after another; all of them simple in their early stages, though perhaps highly specialized later. The substantiation of his finding by Oken, in 1806, stimulated activity in the field of embryological research. Baer was the most successful of these investigators. His contribution led to the discovery of the three germinal layers on the germ disc of all the higher animals: namely, the ectoderm, the mesoderm, and the endoderm.

From the ectoderm arise later the nervous system, important parts of the sense organs, the outer layer of the skin, and some others; from the endoderm, the lining of most of the digestive tract, and such outgrowths of the digestive tube as the liver, pancreas, and the lungs; and from the mesoderm, the muscles, bones, blood system, kidneys and so on.

Baer also first discovered the human ovum, a tiny cell in the Graafian follicle $\frac{1}{125}$ inch in diameter.

Ten years after Baer had given a firm foundation to embryological science by his theory of germ layers, a new task confronted it on the establishment of the cellular theory, in 1838. What is the relation of the ovum and the layers which arise from it to the tissues and cells which compose the fully developed organism? The correct answer to this difficult question was given about the middle of this century by two distinguished pupils of Johannes Müller—Robert Remak, of Berlin, and Albert Kölliker, of Würzburg. They showed that the ovum is at first one simple cell, and that the many germinal globules, or granules, which arise from it by repeated segmentation, are also simple cells. From this mulberry-like group of cells are constructed first the germinal layers, and subsequently, by differentiation, or division of labor, all the different organs. Kölliker has the further merit of showing that the seminal fluid of male animals is also a mass of microscopic cells.

Thus it was proved that both the materials of generation, the male sperm and the female ova, fell in with the cellular theory.[1]

Forms of Reproduction.—From the standpoint of nature there are three main considerations for any succession of individuals: (1) the individual must be born, (2) it must grow to maturity, and (3) it must reproduce in order that the cycle may be endless. Reproduction is the most vital consideration in nature. It simply cannot fail, and the adaptations to prevent failure are almost endless.

There are two general types of reproduction, namely, asexual and sexual. Under the former are included such types as fission or division, and budding. Under the latter those of:

Parthenogenesis—female hatching young from unfertilized eggs.
Pædogenesis—reproduction by young or larval animals (may be parthenogenetic.
Hermaphroditism—both sexes in one individual.
Unisexualism—requiring combined function of two individuals of opposite sex.

In all the higher animals, unisexuality prevails, the union of male and female germ cells, produced by the two separate entities, being necessary for the production of a new individual. All the marvelously specialized organs, in both male and female, for accomplishing this result have had a common origin, and although the differentiation probably began millions of years ago, there still remain many similarities between the male and the female reproductive organs. The reproductive organs of one sex have their homologues in the other, although each has been specialized for its respective function. The genital ridge, the first indication of sex organs in the embryo, is much alike in both male and female of the higher species for a considerable time before there is specialization.

It will be the purpose in this and the following chapter to study the principles underlying reproductive physiology. It is not the purpose to attempt to develop veterinarians, however desirable that might be from a breeding standpoint, but to impart to the breeder intimate knowledge of the principles underlying reproduction, in order that he may practice his profession wisely and understand and counsel with the veterinarian when it becomes necessary to call upon the latter.

[1] HAECKEL, E., The riddle of the universe, p. 58, Harper & Brother, 1901.

Testicles.—The primary, or essential, organs of reproduction in the male are the testicles, since their function among others is to produce spermatozoa. In farm animals, these two glands lie outside the body cavity in a sac termed the scrotum. In some

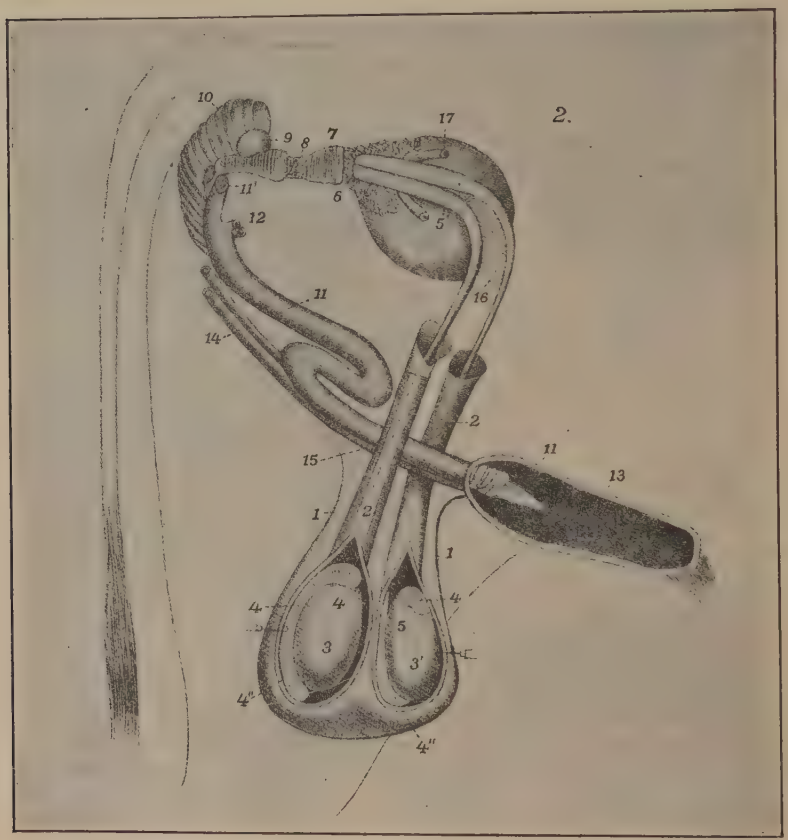


FIG. 17.—Generative and urinary organs of bull. 1, scrotum; 2, spermatic chord; 3, testicle; 4, epididymis (globus major and minor); 5, vas deferens; 6, vesicula seminalis; 7, membranous portion of urethral canal covered by Wilson's muscle; 8, part of prostate gland covered by Wilson's muscle; 9, Cowpers gland; 10, accelerator urinae muscle; 11, penis; 12, cut suspensory ligaments of penis; 13, sheath, laid open; 17, ureters. (*From U. S. D. A. Diseases of Cattle.*)

animals, *e.g.*, the elephant and the anteater, the testicles remain in the abdominal cavity, while in others, *e.g.*, most of the rodents and the hedgehog, they descend periodically during the breeding season into the scrotum, from whence they are again withdrawn into the abdominal cavity. In the stallion, bull, boar, and ram,

the testicles communicate through the inguinal canal with the pelvic cavity, where accessory organs and glands are located. A weakness of the inguinal canal, which incidentally is probably heritable, sometimes allows part of the viscera to pass out into the scrotum, this derangement being known as scrotal hernia.

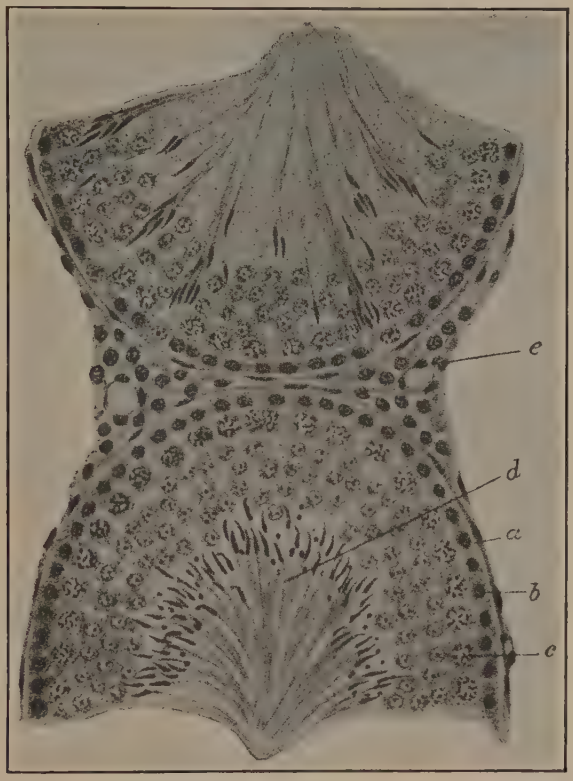


FIG. 18.—Section through seminiferous tubules. *a*, basement membrane; *b*, spermatogonium; *c*, spermatocyte; *d*, spermatozoa in cavity of tubule; *s*, interstitial tissue containing blood vessels. (*From Marshall. The Physiology of Reproduction. Longmans, Green & Co.*)

The testicles are composed of blood vessels, nerves, interstitial, and secreting tissue. The secreting tissue is in the form of minute tubules (seminiferous tubules) which with the interstitial tissue make up the bulk of the testicle. Secretions from these tubules pass along into the efferent ducts (15 to 20 in the horse) which lead out from the testicle. The spermatozoa arise through two rapid cell divisions whereby one cell at the basement membrane of the tubule after enlargement and growth divides into

four functional spermatozoa. The first of these cell divisions is known as the heterotypic division because the two secondary spermatocytes which arise from the primary spermatocyte are different from the latter, having gone through the process of synapsis and the number of chromosomes having been reduced to one-half the normal number for the species. The second cell division is known as the homotypic division because each of the two spermatids that arise from each of the secondary spermatocytes are identical with the parent cell. The spermatids soon develop into functional spermatozoa which pass along through the tubules and out into one of the efferent ducts.

The other principal constituent of the testicle is the interstitial tissue. Secretions from this tissue have a very marked effect on the body. It is this secretion which stimulates the development of the secondary sexual characters. Recent experiments on animals and man indicate that the substitution of testicular glands from a younger subject, or the severing of the tubes leading from the testicles causing an atrophy of secreting tissue and an increase in interstitial tissue, may bring about a regeneration in the subject and retard senility.

Epididymi.—The efferent ducts or vasa efferentia enter the heads of the epididymi. Each epididymis consists of a head region at the top of the testicle, a body region midway and a tail region at the base of the testicle. The epididymis is a tube leading down the outside of a testicle to its base. Its function is to provide a passageway for the spermatozoa. Spermatozoa when secreted are stored in the epididymi and the vasa deferentia. The size of the storage space at the base of the vas deferens is generally thought to be inversely proportional to the length of time required for copulation.

Vasa Deferentia.—Leading from the epididymi and in continuation with their canals are the vasa deferentia. These tubes pass up through the inguinal canals and are the tubes which are severed in performing vasectomy for the purpose of rendering the subject sterile. In structure the walls of the vasa deferentia are thick and the lumen small, giving the tubes a firm cord-like character. The vasa deferentia empty into the urethra which, proceeding through the penis, completes the passage from the testicles to the exterior.

Vesiculæ Seminales.—These are the largest of the three pairs of accessory glands of reproduction in the male. They are

located in the pelvic cavity at the ends of the vasa deferentia, being an outgrowth of the latter at their urethral end, and each connects with the urethra by means of ducts. They vary in size according to the animal and the species, in the horse being 6 to 8 inches long and about 2 inches in diameter, and in the bull 2 to 3 inches long and up to 1 inch in diameter. They are lacking in the carnivora. The function of the vesicles, while not fully understood, is thought to be the secretion of a protein fluid which furnishes a medium for the transference of the spermatozoa.

Prostate.—At the neck of the bladder, surrounding the urethra and connecting with it by many small ducts, is the prostate gland. The secretion of this gland is viscid and contains proteins and salts, concretions of the latter often causing an inflammation or prostatitis in old subjects. The actual function of this secretion is not wholly known, though it is said to precede the spermatozoa at copulation, cleansing the urethra of urine or other material which might be injurious to the delicate spermatozoa.

Cowper's Glands.—Cowper's glands, two in number, are situated on either side of the pelvic portion of the urethra with which each communicates by means of small ducts. These are small glands whose function, though not wholly known, is no doubt similar to that of the prostate. It has been observed that the activity of the spermatozoa is increased by the secretions of these accessory glands.

Penis.—The remaining portion of the male reproductive organs consists of the penis. This organ, besides conveying urine to the exterior, has the further function of conveying spermatozoa into the female genital tract, which it is able to accomplish through the power of erection, whereby the organ can be inserted into the vagina of the female. The penis is made up of erectile tissue which, during the process of erection, becomes engorged with blood. Farm animals exhibit a wide variation in the structure of this organ. In the horse, the end of the penis is rounded and the organ nearly fills the vagina at copulation. In the bull the diameter is much smaller, with the external urethral orifice situated in the urethral papilla at the end and on the left side. The urethral papilla of the bull represents a vestigial filiform appendage. This is well developed in the ram in the form of a slender appendage, which protrudes beyond the glans penis in a twisted manner, and has the function of protruding into the mouth of the womb of the ewe during copulation in order to make

fertilization more likely. The penis of the boar, like that of the horse, is not provided with an appendage or lateral papilla, and the opening to the exterior is situated at the end of the organ and in the center.

Now in resumé, it may be said that the essential organs of reproduction in the male are the testicles, whose function it is to produce spermatozoa; the accessory organs are the vesiculæ seminales, prostate, and Cowper's glands, whose function it is to furnish a medium for the spermatozoa to travel in on their way to impregnate the female and the epididymi, vasa deferentia, and urethra the parts of a long tube which provides a passage-way for the spermatozoa.

Artificial Insemination.—Normally in farm animals, spermatozoa are produced in the testicles, stored in the epididymi, vasa deferentia, or vesiculæ seminales, and at copulation are ejaculated into the vagina or into the uterus of the female. In order to overcome certain forms of sterility in the male or to allow more females to be bred to a certain male, artificial insemination is sometimes practiced with horses and cattle. This is accomplished by allowing a male to serve a female, with a rubber bag placed so as to catch the semen, or else service is allowed in the regular way and the semen secured in a capsule or syringe from the vagina, or else caught in a sterile receptacle from the penis as the male dismounts. As pointed out by Anderson, its greatest service is probably to make fertilization more likely by supplementing the normal service on the same female. If it is to be used at all, extreme care and cleanliness must be observed or more harm than good will result. The quantity of semen ejaculated by a stallion is from 15 to 20 cubic centimeters or more. The number of spermatozoa at one ejaculation is probably hundreds of millions. However, these amounts are in many cases and for devious reasons not sufficient to bring about conception, so that if artificial insemination is practiced and the contents of one ejaculation divided among several females, the likelihood of conception is reduced proportionately.

With some animals, it may be an advantage to supplement natural service by procuring semen from the vagina in a syringe or capsule and depositing this material directly in the uterus. As will be pointed out presently, spermatozoa soon lose their functional activity under unfavorable conditions, and under the most favorable conditions their tenure of life is rather short.

If artificial insemination is to be practiced, extreme care should be used and the semen placed in the uterus of the female to be so treated within an hour after being ejaculated by the male. There would seem to be good reasons against the possibility of impregnating females with semen which has been shipped from some distance and has been some time in transit.

Secondary Sexual Characters.—At sexual maturity, the testicles and the ovaries begin secreting hormones or chemical agents into the blood stream which bring about the development of the typically masculine or feminine structure or body form in general and the particular characteristics associated therewith, *e.g.*, heavy neck, tusks, etc. The question arises as to what part of the testicle in the male is concerned in elaborating this hormone. When testicles are transplanted to abnormal positions, notwithstanding that the ordinary connections with the nervous system are destroyed, the normal development of secondary sexual characters is not arrested. This is also true where vasectomy has been practiced.

In such experiments, however, the spermatogenetic tissue underwent degeneration owing to the semen being unable to escape. The same effect is brought about by exposing the testes to the influence of Röntgen rays, as has been shown more especially by experiments on roe deer by Tandler and Gross. On the other hand, the interstitial cells of the testes were not affected in any of these experiments, and the development of the secondary sexual characters (growth of horns etc.) must be correlated with the persistence and functional activity of these cells. It must be concluded therefore that the interstitial cells are reponsible for the secretion of the testicular hormone.[1]

Castration.—Removal of testicles or ovaries has long been practiced. The common method at present is to remove the testicles after making an incision in the scrotum. This has not always been the procedure, however, as in former times it was the custom to crush the testicles or to destroy the passage from the testicles either by twisting or by tying the spermatic cord. Four major results are obtained through castration: (1) It prevents the procreation of the species by animals deemed unfit for breeding and, inasmuch as such animals are produced even in the best herds and flocks, all breeders at times must have recourse to this practice. (2) It improves the fattening propensities of

[1] MARSHALL, F. H. A., Physiology of farm animals, pp. 163–164, Cambridge University Press, 1920.

animals by rendering them more quiet. (3) It improves the quality of the flesh and reduces the proportion of the poorer cuts of meat, *e.g.*, the shoulder. (4) It increases the weight to which animals may attain either in the fattening or in the draft classes.

Colts are usually castrated at about one year of age, calves at six to twelve weeks, lambs and pigs at two to four weeks. If castration is planned it will be wise to conform fairly closely to the time suggested above, as it can be performed with less trouble at those ages and with the least setback to the animal. Castration of lambs and pigs is simple and easily performed, though with cattle and horses a veterinarian's aid should be procured unless the art is well learned. The cardinal features to be observed in castrating are: (1) to remove all of both testicles, (2) to locate incisions so as to insure drainage, (3) to use sanitary precautions, (4) to prevent excessive loss of blood. Removal of the testicles in animals tends to keep the individual's characteristics in the juvenile state, rather than to throw them over to the female type, which only occurs when ovaries are transplanted into a male. Castration or spaying of the mammalian female does not alter the feminine appearance appreciably.

Semen.—Semen is the entire normal discharge of a male at copulation. It consists of spermatozoa, along with a small amount of a milky fluid from the testicles and epididymi; and the secretions of the seminal vesicles, of the prostate, and of Cowper's glands. The amount of semen ejaculated by farm animals varies with the class of animals. Not many chemical analyses of semen have been made.

According to Slowtzoff, human semen consists roughly of 90 per cent water and 10 per cent solids, which, on incineration, yield about 1 per cent of ash. The solids contain 2.3 per cent of proteins, of which a nucleoprotein, traces of albumen and mucin, and an albumose-like substance have been identified.

The quantitative relation of the various solids in 100 parts of fresh semen can be seen in Table IV.

TABLE IV.—PERCENTAGE COMPOSITION OF VARIOUS SOLIDS IN SEMEN

	AVERAGE VALUES, PER CENT
Water	90.32
Dry residue	9.68
Inorganic salts	0.90
Organic material	8.78
Ether-soluble matter	0.17
Extractives soluble in alcohol and water	6.11
Protein substances	2.09

In the ash K, Na, Ca, Mg, P, Fe, and S have been found.

The quantitative analysis of the ash reveals a remarkably large amount of calcium and phosphoric acid: about 20 per cent Ca and 30 per cent P_2O_5. The amount of calcium excreted in one ejaculation is, therefore, about 0.01 gram, and exceeds that contained in an equal quantity of lime water. Analyses of the semen of other mammals do not appear to have been made, but it is unlikely that there are any essential differences.[1]

Spermatozoa.—In every normal ejaculation, there are millions of spermatozoa. They are continually being secreted in the tubules of the testicles and stored ready to be ejaculated into the female genital tract at copulation. A normal spermatozoön consists of a head, a body, and a tail. The head is usually rounded or pear-shaped and contains the chromosomes; which, together with the chromosomes of the ovum, determine the potential characteristics of the new individual. The body region contains the centrosome which functions in cell division. At fertilization the head and body regions pierce the ovum to perform their functions, while the tail, which has already performed its function in propelling the spermatozoön to the ovum, does not enter the ovum, but is absorbed. Anderson gives the following measurements of spermatozoa, in microns:

TABLE V.—SHOWING MEASUREMENTS OF SPERMATOZOA

	Head	Body	Tail
Stallion	3	1½	24
Bull	5	2	32
Rooster	12	1	40
Man	3	2	24

As found in the testicles or epididymi, the spermatozoa are not very active. It is the remaining portion of the semen, the secretion of the accessory glands as well as the normal secretions of the vagina and uterus of the female, that activates them.

Normal Life of Spermatozoa.—In order to determine the normal length of life of spermatozoa in the male organs, Lewis castrated young boars, removed testicles and cords and kept them at room temperature, 22°C. At the end of 3 hours, 60 to 70 per cent of the spermatozoa were alive, but at the end of 18

[1] MARSHALL, F. H. A., The physiology of reproduction, 283 pp., Longmans, Green & Co., 1910.

hours no live spermatozoa could be found. The same investigator reports that out of a total of twenty-five sows bred and killed thereafter at varying times in order to determine the length of life of spermatozoa in the female genital tract,

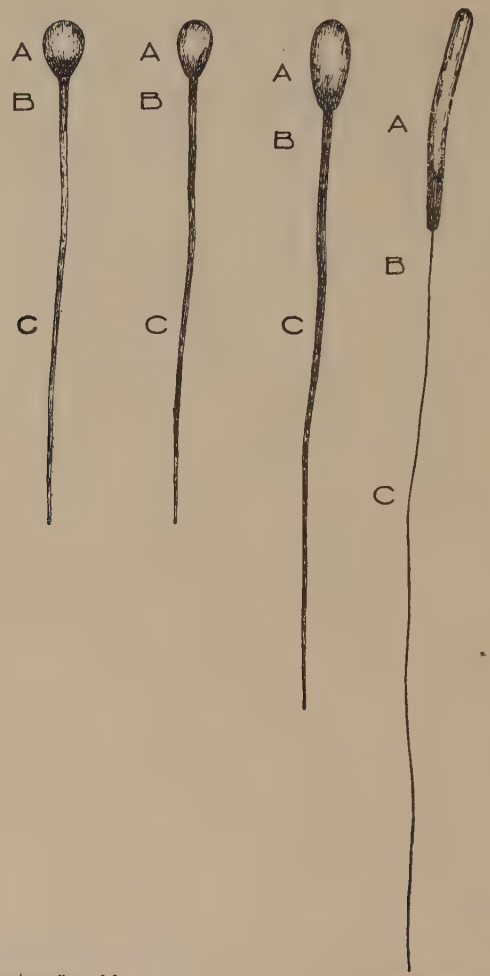


FIG. 19.—Spermatozoön of human, horse, bull and rooster left to right. (*Photo. from Anderson, Ky. Bull.* 239.)

". . . in only three sows in the experiments of 1908 to 1910 could live sperms be found at a greater length of time than 20 hours after breeding. In two cases live cells were found after a lapse of more than 40, and in one case after a lapse of 22½ hours.

The following data are taken from similar work of Anderson to determine length of life of spermatozoa in the female genitalia. Hens were bred and killed 6, 8, and 15 hours after breeding. Live spermatozoa were found in the hens killed at the 6- and 8-hour periods, but none could be found in the one killed 15 hours after breeding. A mare was bred and killed 16 hours after breeding and one feeble spermatozoön was found in the right ovarian tube. A second mare was bred and killed 5 hours after breeding and no live spermatozoa were found. A third mare was bred and killed 5½ hours after breeding and vigorous spermatozoa were found in all parts of the tract as far as the Fallopian tubes 7¼ hours after mating. Referring to this last mare, Anderson states:[1]

> This fact becomes interesting when it is remembered that 6 hours is the average life of the sex cells when kept in the most favorable laboratory condition. It would seem that the fluids of the genitalia when normal have a tendency to prolong the life of the cells. From our work and that of Lewis, already referred to, it seems reasonable to assume that fertilization in mammals takes place in the vast majority of cases within 12 hours after insemination. Rare cases may extend the time to 36 or 48 hours. The spermatozoa after the first 12 hours of life on the mucous membrane of the womb and tubes are liable to become entangled on the surface and to be absorbed.

Based on extensive experimental data to test the effects of various agents on the spermatozoa, Anderson gives the following summary:

1. Spermatozoa of mammals show activity under laboratory conditions for about 6 or 8 hours.
2. Spermatozoa are not especially sensitive to change of temperature and are not immediately injured by sunlight.
3. Spermatozoa are easily injured by acids and alcohols but are not so easily injured by alkalies.
4. Spermatozoa show activity longer in the uterus than under laboratory conditions.
5. The hydrogen ion concentration of the semen appears to have an influence on the activity of the spermatozoa.

All the experimental work that has been done shows that the life of each spermatozoön hangs by a rather slender thread and

[1] Anderson, W. S., Vitality of spermatozoa, *Ky. Agr. Exp. Sta. Research Bull.* 239, 23 pp., 1922.

that its tenure of life even under the most favorable conditions is rather brief, a matter of hours, rather than days. Accordingly, if breeding operations are to be successful, every effort must be exerted to have spermatozoa deposited in the vagina or in the uterus of the females under such conditions, and at such a time, that their function may be fulfilled normally before they perish.

CHAPTER IV

THE FEMALE GENITALIA

It is in the female genitalia that all the higher species of animals spend their prenatal life. To keep these organs in a vigorous state of functional activity is a consideration to which the breeder often pays too little regard. An enormous annual loss is incurred by breeders through failure of females to conceive and while it is unjust to lay all the blame at the door of the females, their share of the total fault is no doubt considerable. "Knowledge is power" and an understanding of the processes involved in fertilization, gestation, and parturition would often enable a breeder to avoid the fatalities which so often threaten individuals before as well as after birth.

Ovaries.—The primary organs of reproduction in the female are the ovaries because their function is to produce ova or eggs. There are normally two ovaries corresponding to the two testicles in the male. These glands are situated in the abdominal or the pelvic cavity suspended in the broad ligament. Their position varies somewhat in different species and in different individuals. In the mare, they are somewhat bean-shaped and 2 to 4 inches in the longest diameter; in the cow, 1 to 1½ inches; in the ewe ½ to 1 inch; and in the sow somewhat larger and more irregular, due to the many protuberances of the follicles and corpora lutea which gives them a shape somewhat like a bunch of grapes. The ovary consists of interstitial, connective, and nerve tissues, blood and lymph vessels, and many thousand vesicles, Graafian follicles, or ovisacs. The latter, found all through the stroma of the ovary, contain the immature ova which when matured are liberated and each may be fertilized by a spermatozoön and produce a new individual. Each ovisac is at first surrounded by a single row of epithelial cells. As development of an ovisac begins, the surrounding cells increase in number and a space is formed between the ovum and the surrounding cells which, becoming filled with a protein fluid, nourishes the developing ovum. The developing ovisac passes toward the periphery of the ovary, finally protrud-

ing from the ovary to the extent of half its size or more preparatory to being liberated. This maturing of the ovum in the ovary occurs at more or less regular times in farm animals and is usually accompanied by estrum or heat.

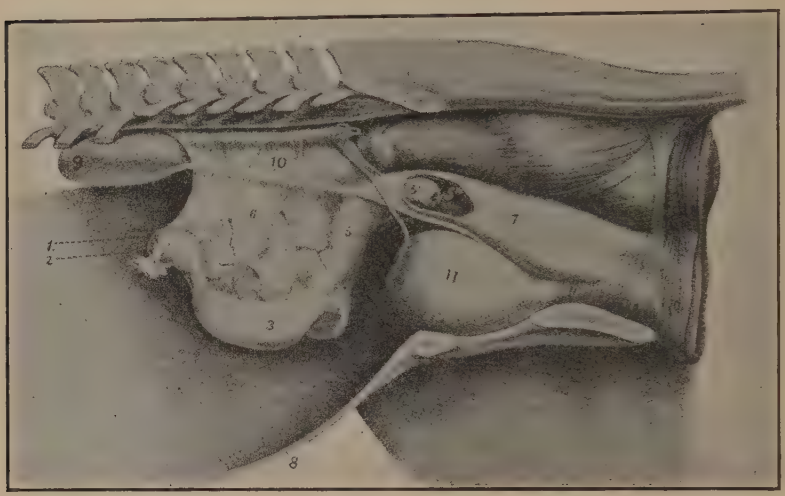


FIG. 20.—The generative organs of the mare. 1, left ovary; 2, Fallopian tube; 3, left horn of uterus; 4, right horn of uterus; 5, body of uterus; 6, broad ligament; 7, vagina; 8, abdominal wall; 9, left kidney; 10, left ureter; 11, urinary bladder. (*From Leisering's "Atlas of the Anatomy of Domesticated Animals."*)

Estrum.—Estrum is the period of sexual excitement in the female. As previously stated, it is accompanied by the ripening of an ovisac in the ovary and by preparation on the part of the other female reproductive organs to receive and nourish the ovum. It is evidenced by the vanishing of the corpus luteum of the previous estrum; the expulsion of the ovum from the ovisac; the engorgement of the uterus with blood and other nutrient fluids; the relaxation of the cervix; the presence of a thin lubricant mucus in the vagina; a marked swelling of the vulva in the sow (less in the ewe, cow, and mare); the characteristic whinnying and friendliness toward the stallion in mares; bellowing and riding of other animals in cattle; loss of appetite and general nervousness in sows and ewes. Most females urinate frequently at this time. The extrusion of blood from the uterus through the vagina and vulva at estrum is almost entirely lacking in farm animals. Williams states that if a cow is bred during a heat period and does not conceive she will subsequently menstruate, while if she does

conceive she will not menstruate. The menstrual period lasts for about 24 to 48 hours in cattle and sheep; 3 days in swine; and 3 to 7 days in mares. As will be pointed out later, this is a most important season, because it is apparently only during this time, in fact, a restricted part of it, that a mare, cow, ewe, or sow can be successfully impregnated.

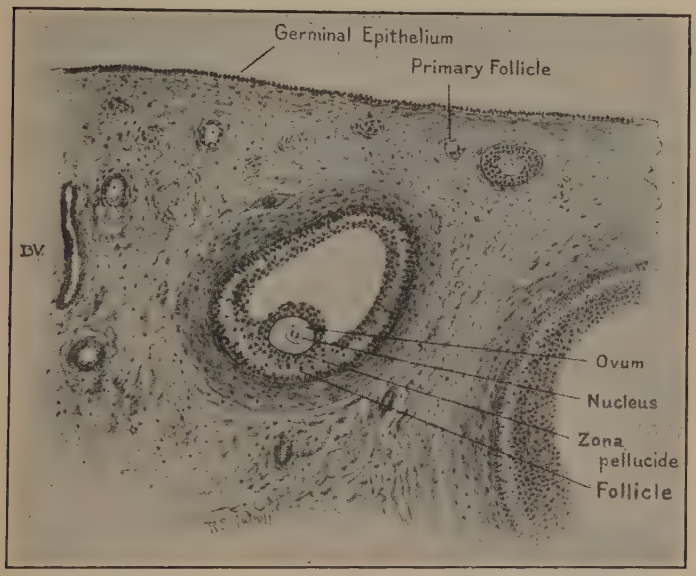


FIG. 21.—Section of ovary of cow showing a follicle, 0.6 mm., with ovum. (*From Diseases of the Genital Organs of Domestic Animals, Williams.*)

Fallopian Tubes.—The Fallopian tubes act as excretory ducts of the ovaries, since they convey ova from the reproductive glands to the uterus. They are not, however, in direct continuity with the glands, but rather partly in contiguity with and partly attached to them.

Their homologues in the male are the vasa deferentia. The Fallopian tubes are firm to the touch and have a diameter of about 0.1 inch. Spermatozoa which are deposited in the vagina or uterus at copulation pass up these tubes to their upper end, where fertilization usually takes place as soon as the ovum is liberated. The fertilized ovum or zygote passes down one of these tubes to find lodgment in a horn or in the body of the uterus. For this latter purpose, aid is derived from the cilia or

microscopic finger-like projections from each of the cells which line the inside of the oviduct and which by a waving motion tend to push the ovum downward. It is apparent that the spermatozoa have to make their way toward the ovary against this force, in other words, have to swim up stream. This they are able to accomplish by means of their tails, which they wave back and forth much after the fashion of a swimming tadpole. Fallopian tubes, which are smaller than the lead in a pencil and greatly convoluted, act in the nature of a seal, thus preventing anything harmful passing down into the pregnant uterus. It can readily be seen, too, that if infection of any sort once found lodgment here it would be exceedingly difficult to combat or to eliminate.

As mentioned above, fertilization usually takes place near the ovary. This process consists of a single spermatozoön from the male coming in contact with the ovum, the entire spermatozoön, except the tail, piercing the ovum and the nuclei of the two germ cells fusing into one nucleus. After fertilization, cell division starts at once, and the fertilized ovum, now called a zygote, descends to the uterus by way of the Fallopian tube. This descent takes several days and under the best conditions is beset with danger.

Horns of the Uterus.—If unharmed, the ovum or developing zygote eventually reaches the next portion of the female genital tract, namely, one of the horns of the uterus. This portion of the genital tract is very large in some species, and extremely small in others. In cattle, for instance, both horns of the uterus are well developed and it is here rather than in the body of the uterus that the embryo is carried all through prenatal life. In the human family, on the other hand, the exact reverse is true, that is, the horns are practically undeveloped and the fetus is carried in the uterus proper. The two horns in either case join the body of the uterus.

Uterus.—As is well known, the function of the uterus is to house the developing embryo until ready for birth. In the nonpregnant state the uterus is rather small, though capable of great enlargement in the pregnant state, due to its muscular structure.

The fertilized ovum upon descending unto the uterus finds itself in a medium rich with food furnished at this stage by the congestion of the uterus with blood and the secretion of nutrient fluid

which the ovum absorbs. Soon two sacs develop around the embryo. One is termed the amnion and the other, which pushes out from the embryo itself through the later so-called navel, is termed the allantois. The part of this latter sac remaining within

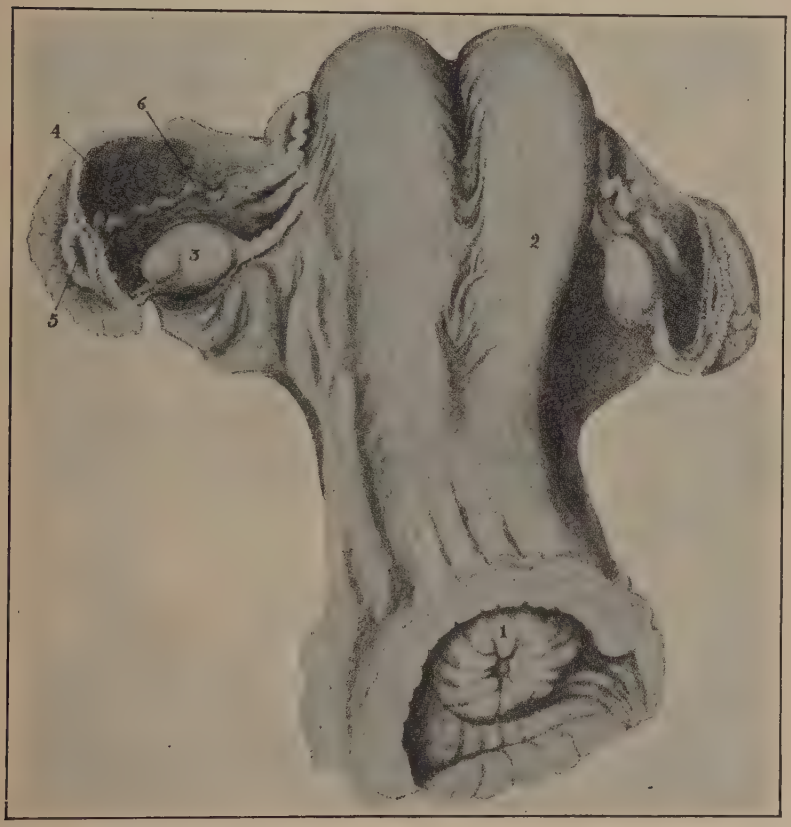


FIG. 22.—Portion of generative organs of cow. 1, os uteri; 2, right cornu; 3, ovary; 4, ovarian ventricle; 5, fimbriated end of oviduct; 6, oviduct. (*From Diseases of the Genital Organs of Domestic Animals, Williams.*)

the embryo eventually forms the bladder. These two sacs are filled with a watery fluid. The fetus is, therefore, guarded against concussion as it floats in the amniotic fluid, the amniotic sac in turn floating in the allantoic fluid. This latter sac and its fluid fill the uterus and its outer wall blends with the chorion or outer surrounding membrane of the embryo to form the placenta.

Placenta.—The nourishment of the embryo now takes place through the medium of the chorion or outer embryonic membrane. This develops finger-like processes which fit into the other finger-like recesses of the uterus of the mother and in this

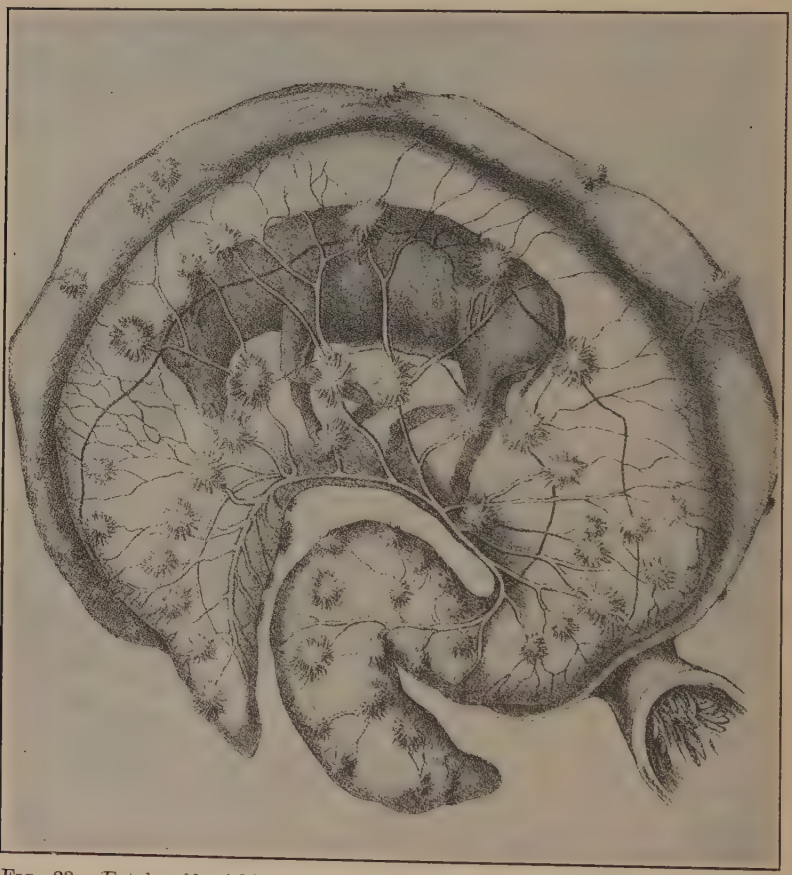


FIG. 23.—Fetal calf within its membranes. (*From U. S. D. A. Diseases of Cattle.*)

way the embryo obtains its nourishment. This interlacing of the maternal and the fetal placentæ is somewhat similar to the connection between two hair brushes stuck tightly together on the bristle sides. These interfittings are localized in cattle at the so-called buttons or cotyledons. From the start the nourishment of the embryo is indirect, being obtained, first, by means of

the yolk sac of the ovum and, later, through the placenta and umbilical cord. Nourishment is carried in the blood of the dam to the placenta, where it transfuses through the capillary walls and reaches the fetal placenta, from whence it is carried to the embryo through the umbilical veins. Bacteria present in the uterus or carried in the blood of the mother may at any stage attack and destroy the life of the embryo, or by separating the connections at the placenta cut off the nourishment of the embryo and eventually cause it to become a foreign body in the uterus, whereupon abortion usually follows.

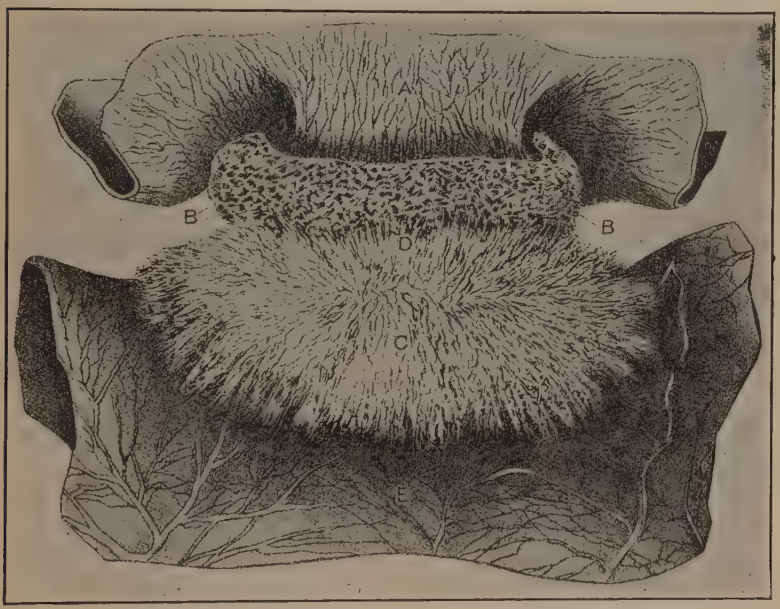


FIG. 24.—Pregnant uterus with cotyledons. *A*, uterus; *BB*, maternal cotyledon; *D*, fetal cotyledon. (*From U. S. D. A. Diseases of Cattle.*)

Cervix.—Beyond the body of the uterus is the cervix, os uteri, or neck of the uterus. Through this narrow constricted portion extends the cervical canal. This may furnish excellent lodgment for various kinds of harmful bacteria. At most times, except at estrum and parturition, the cervix is kept rather tightly closed. It is sealed with a mucous seal during pregnancy, thus sealing up this approach to the uterus, as do the oviducts the other side, thus protecting and safeguarding the embryo. In the cow the cervical canal has many folds and the introduction of

an instrument is accomplished with some difficulty. The cervix relaxes at parturition and the canal is dilated to permit passage of the fetus. It shrinks again to its original size in a few days. During copulation, a motor impulse causes the cervix to dip down rhythmically to the floor of the vagina and this suction-like action aids the passage of the spermatozoa to the uterus. The cervix in the mare is 2 to 4 inches long and the canal comparatively smooth and straight. It terminates posteriorly in the vagina.

Vagina.—This is the organ that receives the penis during copulation, though, as mentioned previously, it is presumed that in sheep the filiform appendage of the penis protrudes through the cervical canal so that the spermatozoa are deposited directly in the uterus. In other farm animals, however, the spermatozoa are probably deposited in the vagina and then must make their way through the cervical canal, uterus, horn of the uterus, and oviduct, a distance of 15 to 25 inches. If breeding difficulties are present in the vagina, it can easily be douched with a mild disinfectant or normal salt solution, though it requires a skilled practitioner to douche the uterus. As noted previously, the spermatozoa are ejaculated into the vagina on the floor of which a depression is found just in front of the cervix. It is from this depression in practicing artificial insemination that the spermatozoa are picked up either with a syringe or with a capsule.

Vulva and Clitoris.—The external female genital organ which connects with the vagina is called the vulva. With the onset of heat, or estrum, this structure becomes congested and enlarged, particularly in the sow, somewhat less so in the cow, the mare, and the ewe. The clitoris, the small erectile organ homologous to the penis in the male, is situated just inside the vulva.

Recapitulation.—To summarize briefly, an ovum is matured in the ovary, a process usually accompanied by the appearance of heat; normally the animal is now bred, spermatozoa being deposited usually in the vagina. These spermatozoa at once start their journey toward the ovary passing up through the cervix, uterus, horn of uterus, and oviduct, or Fallopian tube. Here they await the rupture of the ovum from the ovary. The ovum falls into the Fallopian tube, where it is immediately fertilized by one spermatozoön. This successful piercing of the ovum by a spermatozoön causes a change in the wall surrounding the ovum such as to prevent penetration by any more

spermatozoa. The fertilized ovum now starts its journey down the oviduct to a horn or the body of the uterus where it becomes attached to the wall for its prenatal development. A seal then forms in the cervical canal in order to protect the embryo.

Corpus Luteum.—Upon rupture of the ovum from the ovary, a significant change occurs in the spot from which the ovum came. There remains in this cavity a clot of blood. Immediately from the inside of the cavity a mass of cells starts developing. The wound left by the rupture of the ovum soon heals over and this growth of cells fills the entire cavity and usually protrudes beyond the outer surface of the ovary. If the animal is not bred or fails to conceive, these cells remain chocolate- or liver-colored. If the animal is bred and does conceive, these cells develop a characteristic yellow color giving to the body the name corpus luteum (yellow body). The corpus luteum is usually ½ to ¾ inch in diameter. If the animal has not conceived this persists in the ovary 15 to 20 days when it is absorbed and another ovum is formed, usually in the opposite ovary. If the animal conceives, the corpus luteum persists all through pregnancy and prevents the ripening and rupture of more ova from either ovary and thus also postpones the occurrence of heat until after parturition. In cattle, this body persists usually for 30 to 60 days after calving, when it is absorbed and the ovaries start functioning again; or in other words, the cow comes in heat. If the corpus luteum persists, the animal does not come in heat, and this necessitates the services of a veterinarian in order to dislodge the persistent corpus luteum.

Chronological Order of Reproductive Physiological Processes. It is essential for the student and breeder to keep in mind the various physiological processes concerned in reproduction. In order of their appearance they are: (1) maturation of the ovisac, (2) estrum, (3) copulation, (4) rupture of ovisac, (5) fertilization, or if not, menstruation (in cattle), (6) formation of corpus luteum, (7) pregnancy, (8) parturition, (9) nutrition of young, (10) absorption of corpus luteum.

Time of Ovulation.—The most extensive work on the exact time of ovulation has been done by Dr. L. L. Lewis of the Oklahoma Agricultural Experiment Station.

He selected swine for the experiments because in this class of livestock it is fairly easy to determine the time of the onset of

heat. The time of the onset of heat was noted and the sows were killed at varying lengths of time after the onset of heat in order to study the length of time intervening between the beginning of heat and ovulation.

Table VI indicates these relationships in swine.

TABLE VI.—CONDITION OF OVARIES AND SPERMATOZOA IN EXPERIMENTAL SWINE (*From Lewis*)

Number of case	Date	Hours from time of coming in heat until killed	Condition of the ovaries when killed	Hours from time of breeding until killed	Condition of sperm cells in organs when sow was killed
	1908				
1	May 30	25.5	No follicles ruptured	16	Found live cells
2	July 1	50	Follicles ruptured	....	Was not bred
3	July 10	46.5	No follicles ruptured	22.5	Found live cells
4	Nov. 17	24.5	Ten ruptured, two not	7	Found live cells
5	Dec. 2	29	No follicles ruptured	24	No live sperm cells
6	Dec. 3	11	No follicles ruptured	10	Found live cells
7	Dec. 3	11.5	No follicles ruptured	7.5	Found live cells
8	Dec. 5	42	Follicles ruptured	25	No live sperm cells
9	Dec. 7	51.5	Follicles ruptured	41.5	Live sperm cells
10	Dec. 7	50.5	Follicles ruptured	40.5	Live sperm cells
11	Dec. 8	6.5	No follicles ruptured	4	Live sperm cells
12	Dec. 9	33	Follicles ruptured	24	No live sperm cells
13	Dec. 10	28	No follicles ruptured	19	No live sperm cells
14	Dec. 10	32	No follicles ruptured	....	Was not bred
15	Dec. 12	58	Follicles ruptured	18	No live sperm cells
	1909				
16	Feb. 12	33.5	Eleven ruptured, four not	20	No live sperm cells
17	Feb. 12	30.5	Follicles not developed	21	No live sperm cells
18	Was not in heat and was not bred				
19	Was not in heat and was not bred				
20	Mar. 1	32	No follicles ruptured	16	Live sperm cells
21	Mar. 1	70	No follicles ruptured	16	No live sperm cells
22	Mar. 1	53	Follicles ruptured	47	No live sperm cells
23	Mar. 5	30	Eight ruptured, six not	24	No live sperm cells
24	Mar. 10	29	No follicles ruptured	6	No live sperm cells
25	Mar. 14	36	Follicles ruptured	4	Live sperm cells

DISCUSSION

The total number of sows used in this experiment was twenty-five. The males used were two mature Berkshire boars. Semen was secured from these males and an examination showed that the vitality of the sperm cells was that of the average male hog. In only three cases in the experiments of 1908 to 1909 could live sperm cells be found at a greater length of time than 20 hours after breeding. In two cases live cells were found after a lapse of more than 40 hours, and in one case

after a lapse of 22½ hours. Of the nineteen sows bred and killed, the sperm cells were found dead in 80 per cent of the cases examined where a period of 16 hours or more had elapsed between the hour of service and the time when killed for examination. This estimate does not include those cases numbered from 22 to 25, as they were bred to a boar that was afterward found to be lacking in vitality of semen.

It is not likely that ovulation occurs in hogs to any extent except when accompanied by the usual signs of heat. In all of the cases killed during the period of heat where the sow was considered normal, the ovaries showed that the usual physiological changes were taking place. If the hog was killed early in the period of heat the follicles showed perfect and unruptured, while those from hogs killed a few hours later showed the follicles ruptured. A few sows were killed when not in heat, and in none of these were the follicles found well developed or in condition to liberate the ovum, neither did they show any signs of the recent escape of the ovum from the organ. Variations from the normal no doubt do occur, but it is safe to assume that in the great majority of cases the follicles do not rupture before 30 hours after the period of heat begins. In one case the follicles were not ruptured after the lapse of more than 70 hours, and in another after a lapse of more than 45 hours. As compared with the data obtained from the remainder of the cases examined these are unusual. In no case were the follicles found ruptured during the first 24 hours of heat, and in most of the cases a period of 30 hours elapsed after the first signs of heat before many of the egg cells escaped from the ovary.

By studying the notes and tables under this experiment it will be seen that, as a rule, certain conditions of the organs are found within rather narrow limits of time after the period of heat begins. In only one of the cases were the follicles found ruptured before a lapse of 30 hours after coming in heat.[1]

Vitality of Ova.—A measure of the vitality, or at least the tenure of life of ova, can be secured by breeding animals at varying times after the period of heat has passed. Dr. Lewis also experimented in this field. The general plan was to breed sows at varying times after the period of heat had passed in order to see whether the sows bred at such times would conceive, in other words, whether the ova remained functional after heat has passed and if so for how long. Seven services were thus given on the first day after heat has passed. Two of these services proved successful. None of the latter breedings proved successful.

[1] Lewis, L. L., The vitality of reproductive cells, *Okla. Agr. Exp. Sta. Bull.* 96, pp. 16–17, 1911.

TABLE VII.—RESULTS OF BREEDING SOWS OUT OF HEAT (*After Lewis*)

Number	Times bred	Results of breeding	Time after heat before bred
130	Bred twice out of heat	Breeding successful	1 day in each case
131	Bred twice out of heat	No results from breeding	2 and 1 days
132	Bred twice out of heat	No results from breeding	2 and 5 days
133	Bred three times out of heat	No results from breeding	30, 2, and 2 days
134	Bred twice out of heat	No results from breeding	7 and 10 days
135	Bred three times out of heat	No results from breeding	5, 3, and 2 days
137	Bred three times out of heat	No results from breeding	1, 3, and 5 days
138	Bred twice out of heat	No results from breeding	1 and 2 days
141	Bred three times out of heat	No results from breeding	5, 2 and 2 days
142	Bred three times out of heat	No results from breeding	2, 4 and 1 days
143	Bred four times out of heat	Breeding successful	10, 4, 4, and 1 days
144	Bred three times out of heat	No results from breeding	6, 2 and 2 days
145	Bred twice out of heat	No results from breeding	20 and 5 days

There have been, so far as the writer is aware, no experiments in the higher animals designed to study this particular problem directly. The general presumption that if a female is not in a normal, vigorous state of health, she will not be secreting vigorous healthy ova can be made. The converse of this, however, cannot be assumed because weak ova or ova of low vitality are, no doubt, often produced, due to various disorders of the genitalia not reflected in general health.

While the experimental work regarding normal activity, reaction to various reagents, etc. has firmly established facts regarding spermatozoa, such supporting data relative to ova is very meager. The work of Dr. Lewis has shown that in swine the ova are liberated about 30 hours after the onset of heat and lose their ability to function in reproduction in a day or two. It seems justifiable to assume that the same general principles hold for other classes of livestock. In swine the ova are liberated near the end of the heat period. Probably the same feature also holds with other classes of animals, the heat period lasting about 1 to 2 days in cows and ewes and 3 to 7 or 8 days in mares. A knowledge of these features will enable one to plan his breeding so as to insure success in the greatest degree.

CHAPTER V

FERTILITY

Fertility is the ability of an animal to produce numerous, healthy germ cells each capable of uniting with a germ cell of the opposite sex, thus resulting in the production of numerous progeny.

The question of fertility is second to none in breeding. No demonstration of the scope of its influence is necessary. The worth of any breeding animal is measured by three criteria: namely, (1) its own individual merit, (2) its ability to stamp its desirable characteristics on its offspring, (3) the number of viable offspring the animal is likely to produce. There is probably a small yearly loss in every herd or flock in the country due to lack of fertility, while the total loss from this cause must be very large. For ultimate success, every breeder needs thorough grounding in the principles underlying fertility.

Before proceeding to a discussion of the various factors which promote fertility, it seems wise to consider in broad outline the reproductive phenomena in each of the various classes of farm animals. The initial production of reproductive cells, spermatozoa, or ova, brings about the well-known change in the individual known as puberty.

Puberty.—This is the first indication of sexual maturity or the earliest age at which an animal can beget offspring. In the horse, it occurs at about one year of age, in cattle at four to eight months in sheep at four to six months and in swine at three to five months. The ages stated above are only approximate and will depend upon the manner in which the individual is fed and nurtured, whether forced and made to mature rapidly or allowed to develop more slowly. The practical teaching should be very obvious, namely, that the sexes should be separated from each other at a very early age if promiscuous early breeding is to be avoided. It is not a rare thing for a heifer to drop a calf at fourteen to eighteen months of age or a sow to produce a litter of pigs at seven to nine months, if proper precautions have not been taken to keep

FIG. 25.—Financial King's Interest, a Jersey cow which produced 20 heifers and 1 bull calf. (*Photo. Courtesy American Jersey Cattle Club.*)

males and females separated. No good results and often poor or fatal ones follow such careless management. As noted previously, if males are intended for market, they should be castrated early, and it will then be safe to keep both sexes in the same quarters.

Indications of Puberty.—Signs of the first heat period are evident enough in some species and rather obscure in others. In the mare one notices frequent urination; also neighing and friendliness toward the stallion if he is brought near. In cattle the heifers will be nervous, riding other cattle if opportunity presents, and do considerable bellowing but exhibit little swelling or bleeding at the vulva. Sows at this period will eat sparingly, be extremely nervous, and have noticeable swelling and congestion of the vulva. Ewes that are in heat will be discovered most readily by "turning in" the ram each morning during the breeding season. In all constructive breeding it is essential to know the sire and date of service, which means that one must, except under range conditions, practice "hand coupling" rather than letting the male run at large with the females.

Normal Breeding Season; Age at First Breeding; Gestation.—All classes of farm animals are normally timed by nature to drop their young, in temperate regions, in the spring, mainly because climatic conditions are favorable at this season and perhaps also because there is abundant food both for mother and offspring. This feature brings the normal breeding season as many months previous to spring as the gestation period covers. In horses, therefore, with an average gestation period of 336 days, or about 11 months, the normal breeding season is during the spring months of April, May, and June, though if not bred then, as is sometimes advantageous from the standpoint of farm work, mares will come in heat and breed in the fall and the foal be born the following fall. After foaling, a mare will come in, "foal heat," in 7 to 10 days and normally every 21 days thereafter during the breeding season. Mares are usually bred first at three years of age and if fertile should drop a foal each succeeding year until twelve to fifteen years of age, sometimes for much longer periods.

Cattle will breed at any season of the year. Heifers are generally first bred at from twelve or fourteen to twenty-two or twenty-four months of age, depending on their development, breed, etc. The normal gestation period in cattle is 281 days, or about 9 months. As stated previously, the corpus luteum or

yellow body persists in the ovary of cattle all through the gestation period and 30 to 60 days after parturition. When this corpus luteum is finally absorbed, the ovaries are no longer inhibited but begin producing ova again; in other words, the animal comes in heat and can be bred. When once started, these heat periods recur rather regularly at periods ranging from 19 to 23 days, averaging about 21 days until the animal is impregnated. A cow should produce a calf regularly once a year from the time she is two to three years old until she is twelve to fifteen years of age, or more.

Hogs are usually bred first at eight to nine months of age, depending again on degree of development. No young sow should be bred until she weighs at least 180 to 200 pounds. If farrowed early in the spring and given a fair chance, most young sows will reach this weight by the first part of the following December when they may be bred. This means that the first litter of pigs will be dropped the following March, the gestation period being about 114 days. It is a good plan not to breed these young sows for a fall litter during this first year because they will need opportunity to further their own development. Normally, a sow will come in heat 3 to 5 days after farrowing, but for obvious reasons should not be bred at this time. Sows will come in heat again 3 to 5 days after weaning the pigs no matter whether they are weaned at 4, 5, 6, 7, or 8 weeks, though, for divers good reasons, the pigs should never be weaned at less than 8 weeks. Good sows should be kept in the herd just as long as they continue to produce big litters of vigorous pigs which usually means until they are five to seven years of age.

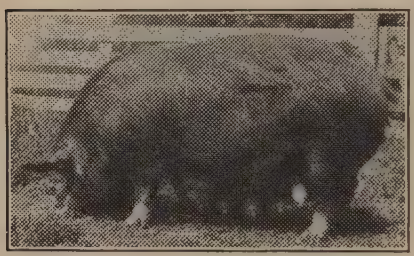


FIG. 26.—Silbirfa Duchess 15th, a Berkshire sow which farrowed 18 litters totalling 172 pigs. The eighteenth litter was farrowed when the sow was 10½ years old. (*Photo. Courtesy American Berkshire Association.*)

In sheep, the normal gestation period is around 147 days for middle- or long-wool breeds, and 152 days for fine wools. This means that if the young are to be born in the spring the ewes must be bred the preceding fall, the normal breeding season being, in fact, during the months of October and November.

Ewes are not ordinarily bred as lambs the first fall of their lives, but allowed to grow out into shearlings or yearlings before being bred, making them eighteen months old at time of first breeding and about two years old when they first lamb. They are bred again the following fall and yearly thereafter until six to eight years of age, when the average ewe's usefulness as a breeder will have passed.

Fertility Inherited.—The fact that fertility is inherited just as are milk production, coat color, or any other characteristic should be clearly realized. Certain strains of hogs always producing large litters in comparison with other strains producing small ones is evidence of this fact, as is also the proclivity to produce twin lambs instead of singles as exhibited by certain breeds and strains of sheep. The now extinct famous strain of Bates Dutchess Shorthorn cattle was highly prized for its excellence, and breeders practiced inbreeding in this family to intensify these favorable characteristics. They were successful in this but from the start the strain was marked by barrenness, the full expression for which the inbreeding also provided, so that after a few generations the strain entirely disappeared. A certain strain or family of animals is more fertile than others, because of its hereditary complex. Inasmuch as it is impossible to examine the hereditary complex and later use it for reproductive purposes, the best one can do is to study the way in which it manifests itself and make his selections accordingly. As will be mentioned later, this feature of fertility should receive due consideration in all selection procedures.

Fertility and Conformation.—When the broad problem of fertility in the animal kingdom is viewed, there is seen to be a general correlation as regards the size of the animal, its gestation period, and its fertility. In those species in which the gestation period is of longer duration than 6 months, the normal number of young at a birth is one while in those species in which the gestation period is less than 6 months several young are usually produced simultaneously. In general the smaller the species the more young are produced. While between species this relationship holds, it does not hold within a given species, that is, the smaller animals within a species are not the most fertile. In fact, just the contrary is true. In swine, for instance, the sows of the Yorkshire breed produce larger litters than those of the smaller Essex breed. The conformation of the former being long, roomy, and deep favors large litters. The same general

proposition holds with sheep. This conformation in all females, namely, roominess of middle, both for feeding and breeding purposes, cannot be overstressed. In the human family the investigations of Galton in England have demonstrated that "daughters are not taller than their mothers, but they are taller than wives in general," which is but another way of saying that the taller women are the more fertile. These conditions are what would be expected because space is required for the normal development and housing of the generative organs and more especially for the successful development of an embryo. A breeder should use due caution in selecting breeding animals, seeing that they are of suitable conformation for their task, as well as that they are selected from a naturally fertile strain.

Fertility and Management.—The harmful effects of mismanagement, in the form of lack of exercise, will be discussed fully in the next chapter. No animal can remain in a vigorous, healthy condition without exercise and, as pointed out previously, while good general condition does not necessarily indicate an abundance of viable germ cells, the latter cannot be exhibited in the absence of the former. The two following examples are taken from recent work on sterility by Anderson at the Kentucky Agricultural Experiment Station.

1. *A Thoroughbred Stallion.*—This stallion is one of the noted sires of thoroughbred horses and was kept at the time of the observation to be mated to a few select mares of his owner. The first examination was made in April at the suggestion of the veterinarian who had the horse under his supervision. He had been mated and remated to a number of mares, with no evidence of impregnation. The microscope showed that he had only a few germ cells and they were of low vitality. He was examined often enough to confirm the first examination. The stallion was relieved of all stud duty for two weeks. His grain ration of oats only was changed to include hot mashes of bran at night. Green stuff was fed also, and a tonic given him.

At the end of 2 weeks the germ cells were abundant and of normal vigor. He was remated to all mares previously bred to him and the remainder booked to him; and he impregnated 91 per cent, a greater per cent than most stallions.

He is a good example of a male temporarily out of breeding condition. The change of food and the use of tonics may not have been the cause of his recovery. He might have regained his potency without treatment, or he might have grown continually worse until permanent impotency set in.

It is mere speculation to suggest the possible causes of the temporary derangement of the sexual functions. Some work done by us on the hydrogen ion concentration of horse semen indicates that it may be due to an exhaustion of certain mineral elements in the animal metabolism. This hypothesis seems to be sustained by the quick responses which this stallion and others have made to a tonic containing phosphorus.

2. *A Thoroughbred Stallion.*—This stallion was found in the midst of a stud season with no mares seemingly settled from his efforts up to that time. In an endeavor to procure a sample of his semen he was given the opportunity to serve a mare. After repeated attempts and failures it was noticed that he was wasting a drop or two of semen, some of which was caught. The microscopic examination showed the number and vigor of germ cells in it to be normal. When this was discovered the problem was simplified to one of getting him to make a proper discharge.

The feed given him up to this time had been crushed oats and hay. His exercise was taken early in the morning under saddle and he was ridden some 8 or 9 miles. The problem was to discover, if possible, the reason why he could not complete the service at the first effort. The writer advanced the theory that with oats only as a grain diet and so much exercise the glands were not secreting enough liquid semen to make the discharge possible when bred to one mare a day. The microscope showed that the testicles were functioning properly for there was a good supply of vigorous germ cells. It seemed that if the prostate gland and seminal vesicles were congested with semen he could not fail to discharge, and that his failure must be because of lack of semen.

To encourage greater activity of the part of the prostate and Cowper's glands, the diet was supplemented by giving a hot bran mash at night and by adding 18 raw eggs a day to his ration. He was given exercise in the morning and rested until the afternoon, when he was mated. The change of time for breeding to the afternoon when his muscles had had time to relax completely, with the more stimulating diets, completely changed the stallion. He very soon was able to make the service at the first attempt. A large per cent of the mares mated to him after this became pregnant and produced vigorous foals the next year, many of which have since become successful race horses. His case is interesting because he represents a nervous class of horses. Stud duty is exacting to them and easily exhausts their energy unless every condition otherwise is favorable. In the case under consideration the restricted diet and the unusual amount of exercise unfitted the animal for breeding purposes. When his diet was changed, his exercise lessened, and a period of relaxation allowed before he was called upon to do his work, it changed him from an impotent to a potent stallion.[1]

[1] ANDERSON, W. S., Sterility in relation to animal breeding, *Ky. Agr. Exp. Sta. Research Bull.* 224, pp. 207–208, 210–211, 1922.

The above results seem to justify the conclusion that the matter of feed and management of breeding animals can be made conducive to fertility. From any standpoint, good bodily vigor which comes from a moderate amount of suitable exercise is desirable. From a feeding standpoint, it has long been realized that protein acts as a cell stimulant as well as being found in the semen and ova. Mineral constituents are also found in semen and in ova. It is easily conceivable that a feeding practice, which did not furnish, along with energy, a sufficient amount and kind of protein, mineral constituents, and vitamines, would seriously curtail an animal's inherent power of fertility.

Flushing.—This is the term applied to the practice of feeding females especially well, just previous to the breeding season, in order to stimulate their reproductive organs to maximum activity. It is a good practice and should apply to males as well as to females. It usually consists of giving an added quantity of high-quality, palatable feeds, especially rich in protein and it should also include fresh, green material. Through its wise use the twinning tendency in sheep can be enhanced as well as the number of pigs per litter in swine, though it would be better for a sow to produce twelve 3-pound pigs and raise them all, rather than twenty-four 1½-pound pigs, the majority of which will probably either die or be killed by the sow.

Pseudo Fertility.—Under this heading are grouped those animals that are apparently always willing to be bred but never conceive. These females are known as nymphomaniacs or "bullers" and because of chronic inflammatory conditions in the ovary continuously remain in heat, though they are in no degree fertile. Here may also be discussed the use of drugs in its relation to fertility. Cantharides and some other drugs do have an exciting influence upon the uro-genital organs. This, however, does not mean that those organs will be able through this stimulation to produce viable spermatozoa or ova. If an animal is infertile other procedures which hold out some hope of success should be instituted, and no stimulating drugs of this nature administered, because they can in no way aid the animal in question in the production of healthy, viable germ cells through which means alone successful reproduction can be instituted.

Clinical Examination of Male Genital Organs.—In diagnosing likelihood of fertility it becomes necessary to examine the reproductive organs. In the male this is somewhat more easily accom-

plished than in the female. With the stallion or bull, it is best done with the animal in a standing position, but in all cases precautions concerning safety must be taken. The stocks are often used to confine stallions while the bull can be handled in the stanchion with a rope fastened around one leg above the fetlock, passed around the other leg and the loose end held. When the animal is restrained, the testicles can be examined from behind. There should be two, of approximately equal size, of a firm, tense structure, and even contour, and they should show no evidence of heat, pain, or swelling. The epididymi and part of the vasa deferentia can also be examined from this position, particular attention being given to the tail or lower portion of the epididymi where infection often lodges. Per rectum, the vasa deferentia can be picked up as they emerge from the inguinal canal and followed along to the vesiculæ seminales, prostate, and Cowper's glands. To examine the bull's penis, he is usually thrown on his side, and his feet stretched out front and back and secured with ropes to stout posts. In this position the Sigmoid flexure of the penis can be eliminated by pushing forward and upward and the glans protruded from the sheath. Moderate traction will bring the penis into view when the retractor muscle has become fatigued and the organ can then be examined for any abnormal conditions. The penis of the stallion can be brought into view by inserting the hand in the sheath, grasping the penis behind the glans and exerting moderate traction until the retractor muscle becomes fatigued.

To complete the examination, it is necessary to secure a sample of semen. This can be done by first thoroughly cleaning out the vagina of a female, letting the male serve her, and then procuring the ejaculation of semen. It should be of sufficient volume, milky white, and viscid, and when examined under the microscope exhibit closely packed fields of normally formed and active spermatozoa. The copulatory act itself should be watched closely to see that it is performed eagerly, completely, and without evidence of pain.

Clinical Examination of Female Genital Organs.—It is entirely possible and often necessary for the veterinarian to examine carefully the structure and condition of the female genital organs of the mare or the cow. As in examining the male, it is first necessary to place the animal in an entirely controllable position from which no injuries are likely to arise either to operator or

animal. When this has been accomplished the vagina and vaginal end of the cervix can be examined by carefully inserting the hand. The nails should be cut back short, and the hand thoroughly cleansed and fingers placed in a cone shape. Forceps can be attached to the cervix and gentle traction exerted pulling it back into view.

Physiologically, the vagina of the cow at estrum and when nearing parturition contains an abundance of clear, rather fluid, highly lubricant mucus. The vagina of the non-pregnant cow in the interval between estrual periods contains a small amount of lubricant mucus. The vagina of the pregnant cow, except when nearing parturition, contains a highly adhesive mucus. These physiologic variations in quantity and quality of vaginal mucus need to be learned by actual clinical observation before the various pathologic contents may be readily recognized.[1]

Rectal palpation is also extremely valuable in determining an animal's genital health and normality. Such rectal examination, after removal of the feces by hand, usually reveals the cervix, 3 to 6 inches long, on the floor of the pelvic cavity between the bladder and the right pelvic wall. This followed anteriorly leads to the somewhat broader and softer uterus. In cattle the body of the uterus is rather short giving rise anteriorly to the two horns of the uterus. These in the cow proceed forward and upward, then turn down and back forming an almost complete circle. Arising from the end of the horns are the oviducts, often difficult of recognition by rectal palpation. They are about $\frac{1}{10}$ inch in diameter, sinuous, smooth, and firm. They pass laterally below and in front of the ovaries, both oviducts and ovaries being embedded in the broad ligament. Lastly the ovaries themselves, situated in the broad ligament, can be palpated. They usually lie on the floor of the pelvic cavity along side of the horn of the uterus.

Examinations such as have been described for male and female when performed by a competent verterinarian while sometimes costly, are invaluable to the breeder and the expense is small compared with that incurred in maintaining sterile animals over periods of months or years, and possibly spreading contamination throughout the herd.

[1] WILLIAMS, W. L., The diseases of the genital organs of domestic animals, 87 pp., Andrews and Church, Ithaca, N. Y., 1921.

Diagnosis of Pregnancy.—The following are indications of pregnancy in animals: (1) failure to menstruate within 24 to 48 hours after copulation (cattle); (2) cessation of heat periods, though in some instances animals that have not conceived fail to exhibit further estrual periods and also some that have conceived do exhibit estrum during pregnancy, probably as Williams suggests because of the atrophy of the corpus luteum; (3) formation of the characteristic adhesive uterine seal in the cervix; (4) presence of normal corpus luteum in the ovary; (5) increased size and functional activity of the uterine arteries; (6) palpation of the uterus per rectum showing it to be firm, tense, and fluctuating; (7) increased size of the female; (8) ausculation of fetal heart; (9) movements of the fetus; (10) generally females which have conceived become more quiet and tend to lay on flesh. It is possible late in gestation to feel the fetus at the base of right flank.

Prolificacy.—"Fertility," "fecundity," and "prolificacy" are used synonymously. "Fecundity" comes from the same root as fetus, and for this reason is more or less restricted in its use and applied to females. "Prolificacy" implies especially frequent or numerous production. In all the higher species the production of any young is contingent upon the union of viable germ cells from both parents. In those species however, which normally produce more than one young at a time, prolificacy is measured through the fecundity of the female, for the reason that a fertile male produces enough spermatozoa at a service to fertilize millions of ova. In swine, for instance, the number of pigs per litter depends not on the boar, provided he is healthy and vigorous, but upon the number of ova which have matured in the sow's ovaries. As noted previously, this will depend upon inheritance, state of nutrition, general size and conformation, handling, etc., of the sow. It is entirely conceivable that the factors tending to prolificacy might be transmitted from a sire to his daughter though the male is in no sense prolific.

CHAPTER VI

STERILITY

Sterility is present to a greater or less extent in all breeds and flocks and entails enormous financial loss annually. A clean fertile herd or flock can be had and maintained, provided the proper thought and effort are expended. The task, however, is not an easy one and requires the most efficient technique for its successful achievement. Only about 60 per cent of mares bred drop living foals, and while the percentage in cattle, swine, and sheep is no doubt somewhat higher, it falls far short of 100 per cent.

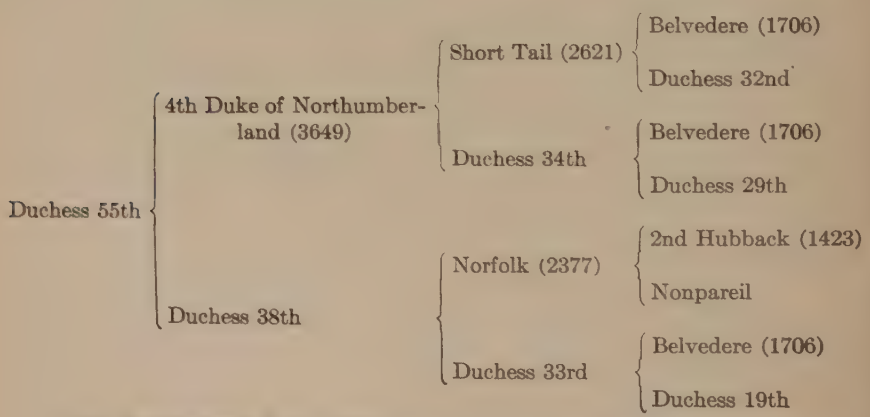


FIG. 27.—Pedigree of one of the latest Duchess cows, illustrating system of close-breeding followed in maintaining the family. Duchess 55th produced two calves.

Sterility Inherited.—Under certain conditions there can be no question but that sterility is inherited just as is any other characteristic. The work of Bridges on Drosophila has proved that a

male of the sex-chromosome constitution XO (due to non-disjunction) is sterile. Evidently the absence of a complete Y chromosome from the genetic make-up of the male in Drosophila

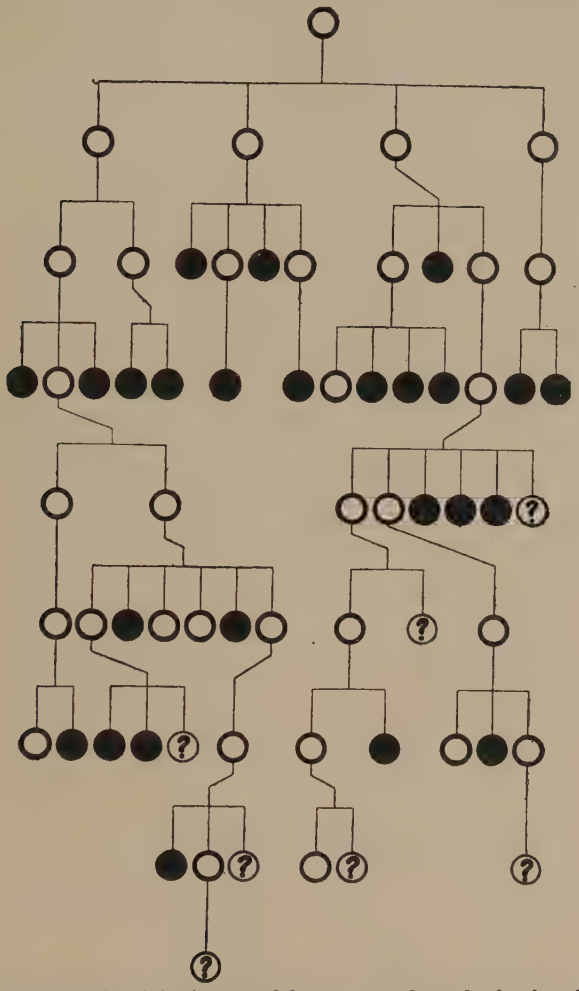


FIG. 28.—Illustrating inheritance of barrenness through the female line of the Duchess family of Shorthorns; barren cows represented by solid black circles. (*From Genetics in Relation to Ag., Babcock and Clausen.*)

produces sterility. Tortoiseshell male cats are also said quite generally to be sterile, presumably because of their genetic constitution, which also incidentally produces their peculiar coat color.

An instance from practical breeding history which appears to belong to this category is that of barrenness in Bate's famous Duchess family of Shorthorns. This family was noted for superior individual excellence, consequently breeders, naturally desirous of maintaining this excellence, followed a practice of close breeding within the family, an example of which is given in Fig. 27. But the family was tainted from the beginning with the curse of barrenness, which such a system of breeding must inevitably preserve. Shortsighted breeders at the time considered it a fortunate circumstance that Duchess cows were so often barren, for it kept down the number of individuals of this favorite strain and resulted in prices correspondingly high. But as a result of barrenness the strain eventually ran out completely. In Fig. 28 an attempt has been made to show diagrammatically how barrenness was inherited in this family. The diagram is not complete, for it includes only the females in the family. Nevertheless it brings out very forcibly how barrenness occurred very early in the family history, and how it reappeared in about the same proportion of the total population throughout its history. Far from showing an intensification of the defect as a result of inbreeding, this diagram merely illustrates the heredity of a defective family trait.[1]

Deformities and Pathological Conditions.—There are a great many deformities and departures from the normal which may render an animal sterile. In the male are found anorchidism, or lack of testicles, and cryptorchism, or the retention of the testicles in the abdominal cavity. All of the former class and most of the latter are sterile. If one testicle is present in the scrotum, the animal is probably fertile, although it is a grave question as to whether or not any animal ought to be used for breeding purposes if it shows genital abnormalities of any sort. Malformations of the penis may render normal service and deposition of spermatozoa in the female genital tract impossible, as may also inflammation or ulceration of any of the male parts. An inflammation may entirely close the passage leading from the testicle and, while service may be normal and semen ejaculated, the latter will contain no spermatozoa and the animal for this reason will be impotent. Inflammation, too, may cause a discharge of pus with the semen, rendering the spermatozoa inactive.

In the female are found various deformities, such as double cervix, double uterus, persistent hymen, strictures, etc., some of which a veterinarian can obviate, provided the worth of the

[1] Babcock and Clausen, Genetics in Relation to Agriculture, pp. 555–556, McGraw-Hill Book Company, Inc., 1918.

animal justifies the expense. In all cases of deformities, the matter of the possible transmission of the deformity or weakness should be considered carefully before deciding to retain the animal in the breeding herd or flock. While, strictly speaking, diseases are not heritable, the susceptibility to many diseases no doubt is and likewise a certain percentage of deformities, if not all of them, would be expected to be heritable, though probably oftentimes they would be carried along in the recessive condition. The safest method by far is to discard for breeding stock those animals which do not score 100 per cent so far, at least, as the normality of their reproductive organs is concerned.

Injuries.—It is possible through faulty management or accident for any animal, no matter how nearly perfect, to become injured. Some horses with spavins, ringbones, etc. might classify here. If they could perform service one would not expect to find the diseased condition inherited. A weak joint could very well be inherited, so that in such cases the question becomes that of determining whether the blemish or the unsoundness is due to inherent weakness or to faulty management. It may, of course, be due to both. Injuries to the penis, testicles, or cords in the male or to the ovaries or other parts of the female genitalia at times cause the animal to become sterile. Injury to the back, legs, or feet may render service impossible on the part of the male or the reception of service on the part of the female.

Mismanagement.—This is one of the most important considerations in the whole field of breeding. Care must be used in searching for the cause of breeding difficulties in order that simple, almost obvious causes be not overlooked in the attempt to locate the trouble in something more complex. The matter of lack of *exercise*, simple enough in itself, causes untold breeding losses yearly. Without a certain amount of exercise, it is impossible to keep an animal in first-class physical condition and it is obvious that if the animal is in poor general condition it will be producing unhealthy or weak spermatozoa or ova. To cite a common example, it used to be the practice to drive or ride a stallion over a large area each spring, serving mares at the various farms *en route*. These stallions were notedly sure "foal getters," averaging 80 to 90 per cent or better. Now practice has changed, mares usually being brought to the stallion, and with this change has come about a marked decrease in the percentage of foals gotten by the average stallion to a point close to

60 per cent. Part at least of this decrease is traceable to lack of exercise. Oftentimes the only thing necessary to change an impotent bull into a vigorous "sure" sire is to work him in a cart or on a treadmill, or in some other way insure his getting exercise. A boar unable to serve successfully can often be brought back into usefulness by putting him out where he will get exercise and lose fat. It is sometimes necessary to drive him to his exercise daily. The same general conditions hold with rams. In successfully managing breeding animals, both males and females, exercise is a point which should receive weighty consideration if success is to be achieved. This matter of exercise or work can, of course, be overdone. It should be realized that with breeding animals one cannot demand full productive as well as reproductive returns at the same time. Reproduction requires energy, which must be subtracted from the amount ordinarily expected of animals not engaged in reproduction. As F. Hoesch has stated: "There is no gain in attaining great service from our animals without lasting maintenance of their health, but rather it is a loss for which it is difficult to compensate."

Unbalanced Physiological States.—There are various unbalanced physiological states which occur in farm animals, rendering them unfit for the procreative process. First there is the matter of feeding. The proper nourishment of the animal is, of course, fundamental if the normal processes of growth, production, and reproduction are to be satisfactory. Just as overfertilization of plants induces overdevelopment of vegetative parts and a paucity or entire lack of seed, so overfeeding of animals is likely to bring about overdevelopment of the somatoplasm at the expense of viable germplasm. No doubt many valuable animals, both male and female, have been ruined from a breeding standpoint by being put into too high condition. The show ring formerly called for this type of fitting, but, fortunately for breeders, this is fast becoming a thing of the past.

This matter of feeding can be overdone of course either way, some animals getting too little feed of the right sort to keep them in vigorous health, others too much. Overfeeding leads to fatness, low vitality, and possibly fatty degeneration of the ovaries or testicles or stoppage of the ducts leading from ovaries and testicles by the packing of fat around them. Improper physiological functioning may and no doubt often does manifest itself as sterility. This refers especially to those dairy cows

which make a huge record one year and then fail to breed for one or several years or perhaps forever. Such animals, overstimulated with high protein feeds, are almost literally burnt out and their period of usefulness shortened. They have also drawn heavily on the mineral reserves of their bodies and cannot be expected to function normally until these mineral reserves have been rebuilt. This rebuilding of protein and mineral reserves can usually be accomplished by an adequate dry resting period of at least 2 months before calving, together with liberal feeding of silage, leguminous hays, and a good grain mixture, such as three parts each by weight of hominy, wheat bran, and ground oats and one part of linseed-oil meal during this time. Males, when used for "heavy" service, need a good supply of nourishing feed rather high in protein to keep their reproductive glands properly stimulated. At other times they should be fed with moderation and not allowed to get thin nor should they be fattened excessively for show or other purposes if their breeding powers are still valued.

Vitamins and Sterility.—The latest word on the effect of feeding on fertility comes from Evans and Bishop of the University of California, whose experiments have demonstrated the presence of a fifth member E of the vitamin family, the other four of which will be discussed under Development in Chap. XVIII. This new vitamin has been found to exist in lettuce and alfalfa leaves, egg yolk, and fresh meat. With all other conditions absolutely controlled, it was found that fat, sleek-coated animals fed on a diet deficient in this new vitamin, called E, were absolutely sterile. This discovery will, no doubt, clear up many formerly puzzling cases of sterility.

Proper Feeding.—Any animal that is producing or reproducing, more especially one that is doing both simultaneously, needs to be properly fed. In the wild state animals lived under natural conditions, having to exercise to secure feed which they found growing wild. Domesticating animals—keeping them under artificial conditions, and feeding them on artificial feeds—has led to many difficulties. In recent years the feeding problem has been thoroughly analyzed and feeds have been shown to be made up of four main constituents. There is, first of all, the question of energy (carbohydrates and fats). Economy dictates that this be furnished from as cheap a source as possible. Second, this energy must be supplemented or balanced with good-quality

proteins. Third, the ration must contain sufficient amounts of minerals. In many instances with cattle a tendency to premature births and retained after-births has been overcome after including such supplements as ground limestone, bone meal, etc. in the ration. Vitamins constitute the fourth essential. One of the first things to be done if breeding troubles arise is to analyze critically the ration being fed and to determine whether there is any likelihood of there being a serious deficiency of any of these four necessary constituents. As will be noted later, the feeder-breeder's problem will be much simplified if he is feeding high-quality, properly cured, leguminous hays.

Sudden Changes.—Sudden changes in the feed and care of breeding animals should be avoided. Changes of feed or of surroundings are apt to induce abortion. If allowed free access to salt, pregnant sows not used to it, are very apt to overeat, resulting in abortion. Any untoward event which upsets the physiological balance of a pregnant female is quite apt to result in abortion. Oftentimes animals transported to foreign countries or animals imported into America are temporarily sterile until they become fully acclimated.

Too Frequent Service.—This question will be discussed at length in the next chapter. Suffice it to say here that too frequent service lowers the number and possibly the vitality of the spermatozoa produced, oftentimes causing temporary, if not permanent, sterility.

Failure to Retain Semen.—Nervous, high-strung females sometimes become so wrought up and excited at the breeding season that they are unable to retain the semen. They arch their backs and expel the semen soon after service. Gentle handling conducing to quietness is indicated and at times cold water applied to the loin region or rubbing the back may be efficacious in overcoming this trouble.

Acid Conditions.—A marked condition of acidity in the vagina will destroy the activity of the spermatozoa almost as soon as deposited. This condition can be ascertained by the use of litmus and may be overcome by douching carefully with a normal salt solution just previous to breeding, care being taken to see that the organs are subsequently thoroughly drained. Spermatozoa are especially sensitive to acid and able to withstand but a very slight concentration.

Purulent Discharges.—In the female, inflammatory conditions of the ovaries, oviduct, horns, uterus, cervix, or vagina, accompanied by a purulent discharge, often render the animal sterile. Such discharges are frequently noticed in breeding herds, and it is a grave danger to the rest of the herd if attempts are made to breed such animals. Many of these cases will respond to treatment properly administered by a competent veterinarian. As pointed out by Anderson, pus may also cause the male to be sterile. He cites the following instances:

A Standardbred Horse.—The stallion in this case had been raced in his 3-year-old form and placed in the stud the next year. He was making a normal season when it was noticed that more mares were returning about June 10 to 15 than should have been expected. A sample of his semen showed a sufficient number of sperm cells, although they were lacking in vigor of movement.

A very large number of small, sphere-like bodies were also present. As the writer had not before seen these bodies in the semen, the sample was taken to the laboratory of bacteriology at the Experiment Station and there examined. It was agreed that the bodies were broken-down leucocytes or pus cells.

On the third day after the first sample of semen was secured, the stallion discharged a considerable quantity of pus with the semen. From that time on the number of pus cells diminished but never during that season entirely disappeared. They became so few in number, however, that the number of sperm cells became normal and their vigor seemed to be undiminished. Except for the few mares mated to him when his semen showed the greatest amount of pus, there were no unusual returns and the following season his mares produced the number of foals expected.

Examinations made the next season of his semen showed a few pus cells, but not enough to affect adversely the number or the activity of the sperm cells. The third year after the disorder was discovered his semen still showed the presence of a small number of pus cells.

Examinations of his testicles on different occasions were made, but we were never able to detect the presence of any inflammation. The stallion served promptly and in the usual way. There was, of course, some center of irritation, perhaps within the genito-urinary tract. No evidence, however, of it could be detected except by means of the microscopic examination of the semen; or at the times when considerable masses of pus were expelled with the semen.

The case is typical of a class, disordered by inflamed glands or an inflamed center in the genito-urinary canal.

A Thoroughbred Stallion.—It was found at the beginning of a breeding season that this stallion had failed to impregnate twenty out of twenty-

five mares bred to him the previous year. The discovery led the owner to consult us. The first examination showed large quantities of pus in the semen. The discharge resembled more a pus discharge than it resembled normal horse semen. Floating in the pus-laden semen were immense numbers of live germ cells. Laboratory examination of the discharge and subsequent ones showed that the spermatozoa quickly lost their vigor. Careful examination of the horse located the seat of the trouble in one of the seminal vesicles. His testicles, epididymis, and vas deferens gave no evidence of abnormality. It appears that these organs were functioning in the usual expected way, but that the partial if not total sterility was due to the seminal vesicle or some other organ discharging large quantities of pus into the semen at the time of ejaculation. The toxic effect of the pus no doubt robbed the sperm of their normal vigor and their ability to produce impregnation.[1]

Lack of Spermatozoa.—Spermatozoa may be entirely lacking in the seminal fluid, due to a variety of causes. In some animals, put into too high condition, spermatozoa are secreted in the testicle, but the excess fat packed around the tubules and tubes leading from the testicles entirely close them so that the spermatozoa cannot escape. Inflammation of the epididymi or vasa deferentia may cause their complete closure, so that spermatozoa, normally secreted, cannot escape at copulation. At times, too, a fibroid degeneration of the testicles is found. This is caused by the overdevelopment of the interstitial tissue of the glands with compensating atrophy of the secreting tissue.

Fibroid degeneration of the testes is a condition frequently encountered. It is thought that young males too highly conditioned on rich protein feeds during their show career are injured for breeding by the process. Whether the cause of fibrosis is due to the feed or not, the condition is not infrequent and the purchaser of a breeding male should always buy him on condition that he is to be found fertile on trial. There is no possible remedy for fibrosis, as the condition of the glands renders the production of sperm cells impossible, because the tubules are transformed into a tough, fiber-like structure.

One of the most dangerous aspects of the condition is due to the fact that the secondary sex glands function in a normal way in secreting semen and the sex desire is not necessarily diminished; consequently animals not capable of maturing a single sex cell may serve as promptly and as often as though they were in good breeding condition and the discharge of liquid semen may be copious.

[1] Anderson, W. S., Sterility in relation to animal breeding, *Ky. Agr. Exp. Sta. Research Bull.* 244: 209-210,213, 1922.

Fibrosis is not the normal condition of old age. It may or it may not be found in very aged males used in the stud. It is the writer's belief that in certain families of almost all breeds of domestic animals there is a tendency to develop a fibroid condition of the sex glands, some in early life and others later in life. Sterility that is due to age and age only is caused by the exhaustion of the glandular material, so that few or no gland cells are left out of which sex cells can be matured. As extreme age comes on the discharge will be less and less and will contain fewer and still fewer sex cells until the time comes when there are too few to expect impregnation to follow. As long, however, as sex cells are formed and liberated, their size, shape, and activity will be identical to those of a younger animal. That is to say, as old age comes on the condition is not in any way reflected in the morphology or activity of the sex cells themselves. Their number may be very greatly lessened and a point reached where there will be no more liberated; but as long as the glands function in their production the sex cells differ in no way from those matured in youth.[1]

Lack of Ova.—While not established experimentally, it is probably true that conditions similar to those discussed in the previous section, tending to cause an absence of spermatozoa in the male, also prevail correspondingly in the female, tending to cause the absence of functional ova in the uterus, though the animal may come in heat and mature ova in the ovary.

Imperfect Spermatozoa or Spermatozoa of Low Vitality.—Microscopical examination of semen sometimes reveals spermatozoa with abnormally shaped parts or with an entire lack of some part, as, for instance, tails. Williams gives the following excellent discussion of this topic:

> For the production of a viable calf, it is necessary that both the male and the female elements be of high vitality, capable of union with each other, and resulting in the formation of an embryo of such high vitality that it is able to survive during its intrauterine existence. It is not uncommon that weak germinal cells are produced. This phase of the subject is particularly accentuated in the case of the male where impotence, sterility, and the production of weak offspring from a given sire are quite frequent. It is a phase of the subject that has received entirely too little attention, and, as common as male infertility is, the disabilities resulting from it are generally considered as due to disease of the cows, even without any effort being made to ascertain the soundness of the bull.

[1] ANDERSON, W. S., Sterility in relation to animal breeding, *Ky. Agr. Exp. Sta. Research Bull.* 244, p. 219, 1922.

As with the ova, the development of the spermatozoa is often interfered with. It may be interrupted at any point, the cause apparently being either an inherent weakness or an infection of a germinal portion of the testicles either at the time of calfhood or at any period following. The greater portion of cases of infertility in the bull are evidenced by demonstrable changes in the spermatozoa, but there are occasionally cases in which these changes cannot be demonstrated, the difficulty being due either to a simple loss in vitality or directly due to an infection

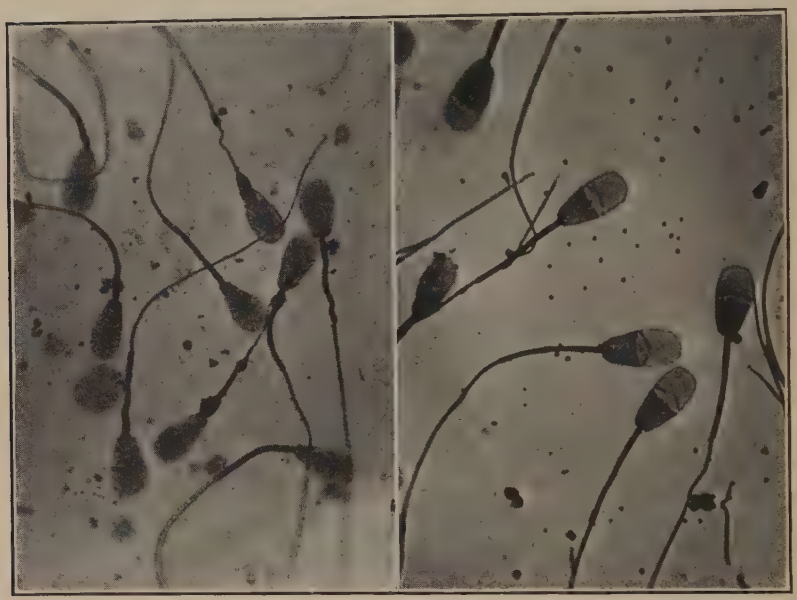


FIG. 29.—Abnormal and normal spermatozoa of bull. (*Photo. Courtesy Dr. W. W. Williams.*)

excreted along with the seminal fluid. The efficiency of the bull is usually dependent upon the extent of these changes. Generally, however, his actual reproductive efficiency is decreased out of all proportion to the changes observed, showing that the reduction in vitality of the cells is usually quite uniform, regardless of the fact that such would not be indicated if judged entirely from the percentage of abnormal cells present.

The following cases illustrate the results that one may, in general, expect following the use of a sire with weakened and diseased germinal cells.

Bull No. 5 was first put into use when a yearling in the fall of 1919. Since then he has been used about four to seven times per month. It

has taken about three services per conception, although he was used on cows which, in general, one should expect to conceive promptly. In the past 5 months, he has been almost sterile; only one or two cows have conceived during this time. On the original examination of this bull, there was a very high percentage of abnormal cells. An examination made in February, 1921, shows a great increase in the number of abnormal cells, they being present now at the rate of about 300 per 1,000. An animal of this kind should not be allowed to remain in service.

When abnormal spermatozoa occur in any quantity I have failed to observe any appreciable improvement afterwards, although I have had under observation for the past 2 years a number of such bulls with abnormal spermatozoa.

In June of last year, I examined in one herd two bulls, both of which had a very high percentage of abnormal cells. With one of them about 50 per cent of the spermatozoa had narrowed head parts, but as at that time this was considered as a nutritional disturbance in the development of the cells which might possibly be improved, he was continued temporarily in service. The breeding records of this herd in the following 8 months have been interesting. This bull has been used twenty-four times. Thirteen pregnancies resulted, of which eight have been aborted. In contrast to this are the records of two other bulls used in the same herd. Nineteen pregnancies have resulted from the use of these two bulls, and to date there has been no recognized abortion from any of the cows served by them.

Bull No. 4 was used in a large herd for about 4 years. All of the spermatozoa delivered were abnormal at the time of each of the various examinations. This bull has recently died, but for over a year prior to his death all of the spermatozoa were non-motile when delivered. His use in the herd, where he was the chief herd sire, was evidently responsible for the major portion of the loss of reproduction. Briefly, the losses from the females with which he was used are as follows:

	1916	1917	1918	1919
Abortion observed, per cent	25.0	21.9	27.0	40.0
Total losses, aborters and sterile cows, per cent	40.0	30.6	80.7	89.5

There is very good evidence with some bulls that the impotence is due to a simple lessened vitality of the germinal cells and not to an infection or any changes that might be the result of an infection.[1]

[1] WILLIAMS, W. W., The reproductive process and its limitation by disease, *Jour. Amer. Vet. Med. Assn.*, Vol. LIX, No. 4, pp. 454–458, 1921.

System of Breeding.—It is well known that the system of breeding in vogue may have a very marked influence on fertility. It is often observed that animals of a strain which has been closely inbred for a number of generations are sterile when mated among themselves but fertile with other non-related strains. In fact, the above statement sometimes applies as well to animals which are not closely related. In a great many of the experiments on inbreeding, there has gradually developed a loss of vigor and a lowering of fertility. For instance, Weismann's and Von Guaita's work with mice gave the following results:

TABLE VIII.—DECREASING FERTILITY IN INBRED MICE

GENERATION	AVERAGE PER LITTER
1–10	6.1
11–20	5.6
21–29	4.2
29 and 30	3.5
31 and 32	3.6
33 and 34	2.9

Similar work by Ritzema Bos on rats gave the following results

TABLE IX.—DECREASED FERTILITY DUE TO INBREEDING

1887	1888	1889	1890	1891	1892
$7\frac{1}{2}$	$7\frac{1}{7}$	$7\frac{12}{17}$	$6\frac{21}{36}$	$4\frac{7}{13}$	$3\frac{1}{5}$

This effect of inbreeding is not universal, however, as King reports on two series of rats (A and B) inbred, litter brother and sister, for twenty-five generations:

Data given for the A series of inbreds comprise 1,752 litters containing 13,116 individuals, or an average of 7.5 young per litter; records for the B series of inbreds include, 1,656 litters, having a total of 12,336 members, or an average of 7.4 young per litter. The two series combined comprise a total of 3,408 litters, which contained 25,452 individuals. For the entire strain the average size of the litter was 7.5 young . . .

A comparison of the data for the inbred strain with data for litter size obtained from a series of stock Albinos reared under the same environmental conditions as the inbred strain shows that each litter of the stock series was relatively smaller than the corresponding litter in the inbred group. For the entire series of 424 stock litters the average size was 6.7 young per litter. This average is 0.8 less than the average for litter size in the inbred strain.[1]

[1] KING, H. D., Studies in Inbreeding, 97 pp., The Wistar Ins. Philadelphia, 1919.

Crossbreeding, on the other hand, where the resulting individuals are not completely sterile, as in the mule, often produces plants or animals that are more vigorous in all respects than their pure parents, and are often more fertile. This increased vigor is termed heterosis or hybrid vigor. The exact cause of these phenomena in inbreeding and in crossbreeding is not fully understood. It has been suggested, however, that the germplasm of all species probably carries some inhibiting factors, which, if true, explains why inbreeding often does result in lowered fertility, because these inhibiting factors are intensified; and why crossbreeding often results in increased fertility, because each diverse parent supplies to the offspring factors which tend to dominate and subdue the expression of the weak characters supplied by each parent.

Sterility of Hybrids.—Among species hybrids there is a wide range of ability to reproduce, namely, from a point of increased fertility over the parents down to a point of absolute sterility. The mule[1] and the hinny, the former a jack-mare cross and the latter a stallion-jennet cross, are both sterile, as are also the horse-zebra crosses. Babcock and Clausen report one reference to fertile male hybrids between the zebra and the ass. The researches of Wodsedalek on the reproductive cells of the mule show abnormal reduction divisions during spermatogenesis, which should logically result in imperfectly formed and functioning germ cells. If the hybrids in any cross have characteristically a different number of chromosomes it is difficult to see how the reduction divisions could be normal and result in the production of functional germ cells. Even if the chromosome numbers were the same in the two species, physiological incompatibility might be present.

In the genus Bos, taken in the wider sense to include the subgenera Bison and Bibos, there are various degrees of sterility consequent upon hybridization. The domestic cow, *Bos taurus*, gives fertile male and female hybrids with the zebu, *Bos indicus*. With the yak, *Bibos gruniens*, the gayal, *Bibos frontalis*, the gaur, *Bibos gaurus*, and the bison, *Bison americanus*, the female hybrids with the domestic cow are fertile, but the males are sterile. The banteng, *Bibos sondaicus*, and the zebu behave like this latter series in giving fertile female and sterile male offspring. In this respect they resemble Detlefson's and Castle

[1] A fertile mule has recently been reported by the Texas A. & M. College.

and Wright's results with species crosses among guinea pigs, the female hybrids of which were fertile, the males sterile.[1]

Davenport observes in regard to hybrids that "it is safe to assume that about all the possible fertile hybrids were long ago produced in nature, and either went down under natural selection, or became good species before they came into our hands."

Free-martin.—This is the term applied to a female-appearing calf born as a twin to a bull calf. The free-martin usually has a

FIG. 30.—The sire and dam of this calf were twins.

vulva and it is to all appearances a female. The vagina, uterus, oviducts, and ovaries are imperfect in varying degrees, rendering the animal sterile. Lillie's work has shown, through a study of embryonic development, that in those cases where, after two ova presumably have been fertilized by a male- and a female-producing spermatozoön respectively, fusion of the embryonic membranes of the twins and anastomosis of the blood vessels occur, the normal development of the genital organs of the

[1] BABCOCK and CLAUSEN, Genetics in relation to agriculture, pp. 557–558. McGraw-Hill Book Company, Inc., N. Y., 1918.

female embryo is inhibited. In case anastomosis of the blood vessels does not take place, the female is perfectly normal, as is usual with the twins of multiple births of all other mammals. Lillie explains the retardation of normal development of the free-martin's sex organs as a result of the action of a hormone produced in the testicles of the male embryo and transferred to the circulation of the female embryo as a result of the anastomosis of the blood vessels of the two embryos. The origin of the free-martin was the stimulus for an interesting investigation by Gowen. Questioning the validity of the hypothesis which would have the free-martin arise as one of a pair of identical twins later to suffer sex reversal, Gowen[1] adduced data from three sources which would seem to refute the idea of identical twins in cattle. These are as follows: (1) the fact that Lillie's investigation showed that in twenty-two cases where both ovaries were secured corpora lutea were present in both and in eleven cases where only one ovary was obtained nine had corpora lutea—the other two may be cases of identical twins or one ovary may have ripened two ova at once; (2) the fact that if identical twins are lacking in cattle the ratio should be 1:2:1 (male twins: male and female twins: female twins) which ratio his figures simulate; and (3) that if identical twins occur in cattle the like sexes of twins should show a greater degree of similarity of color marking than twins of unlike sex or of full sisters which they did not.

Age and Sterility.—When born, animals are sterile, because their reproductive organs have not matured and are not capable of producing viable spermatozoa or ova. Fertility makes its appearance at puberty. If carefully fed and handled, not used overmuch and kept free from infection, a normal animal will remain fertile for many years, the exact period of life and usefulness being determined by (1) inheritance and (2) the rate at which the vital patrimony is spent. Eventually, of course, even though life persists, the power for procreation vanishes. Breed histories furnish examples of animals which have retained their breeding powers over very long periods. Any breeding animal should be kept in the breeding herd as long as it continues to produce numerous, vigorous offspring of high individual excellence.

Abortion.—Abortion is the term applied to premature stillbirths. There are, in general, two sorts of abortion, one caused

[1] GOWEN, J. W., Identical twins in cattle, *Biol. Bul. Mar. Biol. Lab.*, **42** (1); 1–6, 1922.

by injuries, improper feeding, or other things extraneous to the uterus, the other caused by microörganisms which invade the uterus *e.g.*, the Bacillus of Bang.

This latter type of abortion is a moot subject to which many investigators have assiduously devoted themselves, but even yet there remains a great deal to be learned concerning it. It is commonly spoken of as contagious abortion. There may be many organisms capable of being spread from one animal to another which are able, by their growth, to break down the delicate connections between mother and embryo at the placenta, thus paving the way for premature birth. This is a problem which veterinarians alone are trained and fit to handle and any breeder having trouble from this cause will do well to immediately enlist the assistance of the best veterinarian available, but the breeder himself should aid by carefully observing, cooperating, and carrying out the veterinarian's suggestions as well as by individual study and thought. Bulletins on abortion are available from many state experiment stations as well as from the U. S. Department of Agriculture.

The other type of abortion is usually spoken of as sporadic abortion. These cases usually occur singly because of some untoward happening to one or possibly a few animals, but they are not due to an infectious organism. They may be grouped under the following headings:

1. Injuries.
2. Mismanagement.
3. As an accompaniment to an acute feverish disease.
4. Poisoning.
5. Unbalanced physiological states.

An injury severe enough to cause abortion will probably leave external marks as evidence that some such thing has happened. Slipping, crowding through narrow doorways, or being kicked by other animals or generally maltreated by caretakers will often cause abortion and in some of these instances it is difficult to see external evidence of what has transpired.

Mismanagement, such as putting mares at hard, jerky work, is sometimes a cause of abortion. Anderson reports a case of a mare which had been bred but was not thought to be pregnant being served again by a stallion and aborting a few hours later. He calls this an induced abortion.

Abortion, which is an accompanying phenomenon to an acute feverish disease, will generally be recognized as such due to the presence of the disease.

Any poisonous substance which an animal may eat or drink might cause abortion. Ergot, a fungous disease of some plants, has a powerful effect on the uterus and may cause abortion. Symptoms of poisoning will usually be very noticeable and should be readily recognized.

Unbalanced physiological states due to faulty nutrition no doubt cause many abortions. This is particularly true with animals that are hard worked, *e.g.*, cattle making large milk and fat records. Such animals often have to draw on their own body substance for materials not sufficiently supplied in their rations. This may be especially true of minerals, such as calcium and phosphorus. At any rate, the feeding of minerals has been followed by a cessation of abortion in many dairy herds.

Any animal which is not in a normal state of productive and reproductive health should be removed from other animals in order to lessen the danger of spreading possible contagious disease. If trouble arises, it is well to seek the advice of a competent veterinarian. It is unfair to delay overlong before seeking such advice and help and at the same time to expect the veterinarian to perform miracles. Abortion, both sporadic and contagious, costs breeders millions annually. Proper thought and action can lessen these losses considerably.

CHAPTER VII

REPRODUCTIVE EFFICIENCY

Reproductive efficiency connotes the full and effective use of the reproductive powers of all the animals in a herd or flock; in other words, it is a problem of management. For the most part livestock management entails the application of common sense directed both by previous experience and by a knowledge of scientific principles. The more thoroughly the principles are understood and the greater the accumulation of experience the more efficient should be the management.

Service for Immature Males.—There is common agreement on the fact that the body, as a whole, should not be used for hard work until mature. Yearling horses are not put at hard work because it is readily realized that, while some immediate service might be secured from an animal so used, in the long run the loss would overbalance the gain through such a procedure. The general growth of a colt so used would be stunted and it would probably develop some of the common unsoundnesses, such as spavins and ringbones, because its body was subjected to too severe a strain before it had matured and hardened. The same general laws of relative weakness before maturity apply as well to the procreative powers of individuals, and there is no surer way of ruining a promising young male than by allowing him too much service while young and before the reproductive organs have fully matured. Just as in the case of the yearling horse, a temporary benefit, in the form of a few offspring, might be derived, yet in the long run these offspring would have been purchased at a very dear price, because in the process the animal would have been ruined for future breeding service.

Stallions.—Stallions should not be used for service until at least two years of age and at this time only in a very restricted manner. At this age they can serve a few females only, *i.e.*, one service a week for 8 or 10 weeks during the breeding season with at least a full week's rest between services. With well-grown young stallions, the temptation to use them more often is

great, but it is fraught with so much danger of permanently ruining the animal that it should be sedulously avoided. At three years, the stallion can serve twice a week for the 12 breeding weeks, or twenty-five or thirty mares per season. At four years, the amount can be increased to fifty or sixty services and a mature five-year-old stallion can serve eighty or ninety mares during the year. The matter of time and place of service will be discussed for all classes of stock presently.

Bulls.—Bulls at one year of age can be used for light service if desired. Here again extreme care and good judgment must be used and the number of services kept down to ten or twelve, with an adequate rest period of at least a week intervening. At two years of age a bull can serve twenty-five or thirty females, at three years, forty or fifty, and after four years can take care of a herd of sixty to eighty females.

FIG. 31.—The Berkshire Boar, Elimination 314900. Grand Champion Berkshire Boar at the National Swine Show in both 1924 and 1925.

Boars.—Boars, if well grown, can be started in service at eight or nine months of age, but during their first breeding season they should not serve more than once a week, with a full week's rest between services. At a year they can be used a little more heavily, *e.g.*, on fifteen or twenty sows, at eighteen months on twenty-five or thirty, and after two years can take care of a herd of forty or fifty sows if necessary.

Rams.—It is seldom advisable to use a ram lamb for service, though this is sometimes done. The safer plan is to keep the ram out of service until he is at least eighteen months of age, which will come during the second fall of his life. At this time he can

be used on fifteen or twenty ewes and the following year at two and one-half years of age he should be able to serve thirty or forty females and after that as many as eighty or ninety if desired.

Individuality.—In all of the above discussions relating to the various classes of males, the time and the number of services must depend very largely upon the individuality and rate of growth of the individuals concerned. The above are average estimates based on animals that have been well grown.

First Service.—Good judgment should be used in seeing that an animal's first attempt at service is successful. Young males of any class may be seriously injured through carelessness in letting them serve vicious or nervous females without due precautions having been taken to see that the young inexperienced male is not subjected to unnecessary risk. With stallions this is particularly important and under these conditions, if not always, strong hopples should be used on a mare. As an example of the harm which may result from carelessness at this time Anderson cites the following case.

A Thoroughbred Stallion.—When this stallion was observed he was beginning the second season in the stud. He had been mated to thirty mares the previous season and only 1 proved to be in foal.

The statement was made to us by his owner that in making one of his first services he fell and severely injured a vertebræ of his tail. After this injury he did not, it was reported, serve close. He would barely enter and discharge close to the vulva.

When he was allowed to serve a mare in our presence the story told of his service the previous season was confirmed. He had formed the habit of entering but a short distance, discharging, and, of course, drawing out the discharge as he came down. The semen was found to be without fault. The barren mares, a great loss to the farm, were caused by his not giving a better service. Semen deposited just within the lips of the vagina will be wasted on the withdrawal. Frequently stallions are guilty of this fault, and when it happens the service should not be counted but the mare remated.[1]

If there is great discrepancy in size or weight a breeding crate or rack should be used in order to facilitate service and to establish the young male's confidence in himself. Rough, uneven, or stony ground should be avoided as a place for service, for obvious reasons. It is a good practice with any class of animals to reserve

[1] ANDERSON, W. S., Sterility in relation to animal breeding, *Ky. Agr. Exp. Sta. Research Bull.* 244, 210 pp., 1922.

a certain place for actual service, and this should in no case be the stall or pen of the male, as such practice is very apt to lead to the development of harmful habits in the male. Such a breeding pen should be out of sight and out of contact with the rest of the herd. It should be kept clean and constructed so as to avoid all possibility of accidents.

Time of Service.—The time of service is also an important consideration. In cattle it should come on the one day on which the females of this class are in heat. In the case of sows, because the ova are not liberated from the ovary until 30 hours or more after the initial onset of heat, it is generally best to breed on the afternoon of the second day of the heat period. With the mare, with a heat period varying from 3 to 9 days and the exact time of ovulation being still unknown, it is a problem to know just when to breed. Some authorities advise letting the stallion run with the mare during the breeding season. Under these conditions he will probably serve more than once and thus make conception more likely. The usual practice is to breed mares on the afternoon of the second or third day of the heat period. If two services can be given without too great a tax on the stallion it would seem advisable that they be given on the second and fourth days of the heat period. The ram is usually turned in with the ewes for a short time each day during the breeding season.

In any event the male should not be allowed to serve directly after feeding. Immediately preceding either of the daily meals is a good time for service. If it should become necessary to have a male serve twice during one day it is well to arrange the services as far apart in the day as convenient.

One Service Sufficient.—Reproductive efficiency implies that the best possible use is to be made of the breeding powers of all the animals concerned. In the case of the male this immediately rules out the practice of allowing a male to serve a female more than once at a given time except as noted with mares, though here two services are not usually allowed on the same day. If the first service is complete in every way, a second service is superfluous. It is a wasteful practice so far as the male is concerned. At each service where ejaculation occurs within the female organs there are deposited from 50,000 to 300,000 spermatozoa in each cubic millimeter of semen, and as the amount of semen varies from 15 to 20 or more cubic centimeters, it can readily be seen that there are millions of spermatozoa deposited

at each service. Only one spermatozoön functions in fertilizing an ovum, so that if none of the millions of spermatozoa of the first service, provided it is a complete, satisfactory service, can fertilize the ovum, it is futile to expect that any of the second might accomplish this result. Mere numbers are amply supplied at the first service and no number of further services at this time will make fertilization any more probable, and the continued excitement may cause the female to expel all the spermatozoa that have been deposited by previous services. Discussing this point in horses Anderson says:

> The fact remains, however, that a very great percentage of barrenness in mares is not due to disease or disorders but to the highly artificial method of mating horses. If a band of brood mares are turned into the pasture with a potent stallion, he will have foals by close to 90 per cent of them. Our best breeders rarely exceed 50 or 60 per cent. In the pastures the stallion will mate with each mare many times during one heat period, while under control a mare rarely gets more than one service. One would be sufficient were it made at the right time with reference to the liberation of the egg; but the time of liberation is one of nature's secrets not yet discovered by man.
>
> There can be no doubt that the time of the shedding of the egg varies with the individual mares, the same mare, perhaps, behaving differently at different times. Assuming that such is the case, it is hopeless to expect a solution of the problem as long as the present method of breeding is employed.
>
> The universal custom of horse breeders is to mate a brood mare, if she does well at foaling time, on the seventh, eighth, or ninth day after dropping a foal. Most breeders prefer the eighth day if the services of the stallion can be secured on that day. Experience shows that this time after foaling is the right time in which to get the greatest number of pregnancies. If it were possible to give two services to a mare with foal at side, in order to double the chance of obtaining pregnancy, they should be given on the eighth and tenth days, or seventh and ninth.[1]

Results of Excessive Service.—Experiments have been carried on at the Oklahoma Experiment Station by Dr. L. L. Lewis on the number and vitality of spermatozoa secreted by males under various conditions. When excessively used for service the number of spermatozoa ejaculated by a male diminishes rapidly. One stallion produced 65 cubic centimeters of semen containing 131,000 spermatozoa per cubic millimeter at the first service and during 9 successive days, on which the stallion served once each

[1] Anderson, W. S., Sterility in relation to animal breeding, *Ky. Agr. Exp. Sta. Research Bull.* 244, pp. 225–226, 1922.

day, the amount of semen and number of spermatozoa declined steadily so that the service on the ninth day produced only 5 cubic centimeters of semen and about 6,000 spermatozoa per cubic millimeter. In another stallion the number was reduced from 232,000 to 43,000 spermatozoa per cubic millimeter over a period of 10 days during which one service was allowed daily. Hays of the Wyoming Experiment Station concluded as follows from his experiments allowing males very heavy service. The properties of semen, as regards its fertilizing power, may be affected by excessive breeding service. The certainty of pregnancy declines with heavy service. The size of litters seems to decline under extremely heavy breeding. The pregnancies that result under heavy service of the male are as large, healthy and grow as fast as others produced under lesser service, though there are not so many of them. The conclusions to be drawn from the above data are that the reproductive powers of animals are not limitless and that they at all times will respond best to careful husbanding.

Preparation for Breeding.—Besides making the external conditions conducive to the success of a young male's first service, strict attention should also be given to the internal conditions of the female genital tract. If, as should always be the case, the young male has come from healthy parents, has grown up in a clean environment, and has been furnished suitable feed, he should reach puberty strong and uninfected. If this is true one cannot be too careful in guarding him against infection. The male should be examined by a competent veterinarian and, if judged sound, is ready for service. He should be allowed to serve only healthy females. The pernicious practice of allowing healthy young males to serve females which have been unable to conceive from one or several previous services cannot be condemned too severely, though it is often practiced even when the female has a purulent discharge. Infection is all too prevalent and must be guarded against continually. A clean herd can be had if due care is exercised, and when this end is once attained its health should be guarded diligently in every detail.

Reproductive efficiency in the female is perhaps even more difficult to maintain than in the male. The female genital tract presents a relatively larger surface that may become infected, as well as more favorable places for bacteria to lurk. The ovaries themselves may be diseased or covered with cysts and they are more difficult to examine than the testicles in the male.

A complete examination of the female genital tract is possible at least in mares and cows and may be given periodically in order to detect the first indications of trouble. An excellent place for disease to lurk is in the small convoluted Fallopian tubes leading from the ovaries to the uterus, this trouble being known as salpingitis. Further down the horns of the uterus or the body of the uterus may be infected, giving rise to various forms of metritis often accompanied by a discharge of pus. The narrow, contracted cervix or neck of the uterus may be the seat of infection. Infection may also lurk or an acid condition be present in the vagina, and in either case would no doubt destroy the spermatozoa deposited by the male.

FIG. 32.—Baron's Helen 2nd a sow which raised two litters of pigs in 1924 as well as being made Grand Champion Berkshire Sow at the National Swine Show. She was reserve Grand Champion in 1925.

Flushing.—Flushing of the females is often practiced for a week or two prior to the breeding season. This consists of feeding the female a little more heavily on high-protein feeds and, if possible, on succulent feeds, these acting as stimulants on the animal body. The purpose of flushing is to stimulate the ovaries to the production of a large number of healthy, viable ova. This practice is used most extensively with ewes and sows and is known to work successfully, though there is no reason to suspect that it would not be equally successful with other classes of livestock were this deemed advisable. The tendency to produce twins in sheep or large litters in swine may be hereditary, but this statement does not imply that the character in question, or perhaps any character, is not subject to a greater or less degree of modification, as such an interpretation would not be in keeping with experience.

Prerequisites to Healthy Offspring.—For the production of strong, healthy offspring it is first necessary that strong, healthy individuals be selected to act as parents. In order to be sure of this first prerequisite, breeders will often have to enlist the aid of a competent veterinarian, who, by a thorough examination of the genital organs of both parents, and also possibly by an inspection of the spermatozoa produced by the male for their number, activity, normal structure, and so on, will be able to render a clean bill of health or not, as the case may be, for the animals in question. The pregnant female should be maintained in a healthful, clean environment, she should receive suitable, properly balanced feeds, have a sufficient amount of sunshine and exercise, and not be required to do too much in the matter of production while engaged in her principal occupation, reproduction.

The breeding herd is a constant care and the breeder must be quick to detect and combat the first signs of an attack by an invading germ. To do this successfully often requires periodic examination of all the animals in the herd by a skilled veterinarian. The only really successful way to combat trouble of any sort is to anticipate it.

Reproductive efficiency can be maintained through care in selecting healthy individuals and in feeding and managing them so that they may fulfil in a normal way the processes of reproduction. The offspring must be protected from infection from the moment of birth on through its entire life. In return for such feeding and care there may be expected a normal, moderate amount of reproductive service from both males and females, in addition to the productive service which they may be rendering.

TABLE X.—REPRODUCTIVE PHENOMENA

	Age at puberty	Normal breeding season	Age first bred	Length of heat period	Length of gestation period	Rebred after parturition
Horses	10–12 months	April to July	3 years	3–7 days	336 days	7–10 days
Cattle	4–6 months	Any time	15–30 months	1 day	281 days	21–90 days
Sheep	4–5 months	September to December	18 months	2 days	147–152 days	Next fall
Swine	3–5 months	December and June	9 months	3 days	114 days	3–5 days after weaning pigs

TABLE XI.—GESTATION TABLE

Date bred	Mare, 336 days	Cow, 281 days	Sow, 114 days	Ewe, 147 days
Jan. 1	Dec. 3	Oct. 9	Apr. 25	May 28
Jan. 6	Dec. 8	Oct. 14	Apr. 30	June 2
Jan. 11	Dec. 13	Oct. 19	May 5	June 7
Jan. 16	Dec. 18	Oct. 24	May 10	June 12
Jan. 21	Dec. 23	Oct. 29	May 15	June 17
Jan. 26	Dec. 28	Nov. 3	May 20	June 22
Jan. 31	Jan. 2	Nov. 8	May 25	June 27
Feb. 5	Jan. 7	Nov. 13	May 30	July 2
Feb. 10	Jan. 12	Nov. 18	June 4	July 7
Feb. 15	Jan. 17	Nov. 23	June 9	July 12
Feb. 20	Jan. 22	Nov. 28	June 14	July 17
Feb. 25	Jan. 27	Dec. 3	June 19	July 22
Mar. 2	Feb. 1	Dec. 8	June 24	July 27
Mar. 7	Feb. 6	Dec. 13	June 29	Aug. 1
Mar. 12	Feb. 11	Dec. 18	July 4	Aug. 6
Mar. 17	Feb. 16	Dec. 23	July 9	Aug. 11
Mar. 22	Feb. 21	Dec. 28	July 14	Aug. 16
Mar. 27	Feb. 26	Jan. 2	July 19	Aug. 21
Apr. 1	Mar. 3	Jan. 7	July 24	Aug. 26
Apr. 6	Mar. 8	Jan. 12	July 29	Aug. 31
Apr. 11	Mar. 13	Jan. 17	Aug. 3	Sept. 5
Apr. 16	Mar. 18	Jan. 22	Aug. 8	Sept. 10
Apr. 21	Mar. 23	Jan. 27	Aug. 13	Sept. 15
Apr. 26	Mar. 28	Feb. 1	Aug. 18	Sept. 20
May 1	Apr. 2	Feb. 6	Aug. 23	Sept. 25
May 6	Apr. 7	Feb. 11	Aug. 28	Sept. 30
May 11	Apr. 12	Feb. 16	Sept. 2	Oct. 5
May 16	Apr. 17	Feb. 21	Sept. 7	Oct. 10
May 21	Apr. 22	Feb. 26	Sept. 12	Oct. 15
May 26	Apr. 27	Mar. 3	Sept. 17	Oct. 20
May 31	May 2	Mar. 8	Sept. 22	Oct. 25
June 5	May 7	Mar. 13	Sept. 27	Oct. 30
June 10	May 12	Mar. 18	Oct. 2	Nov. 4
June 15	May 17	Mar. 23	Oct. 7	Nov. 9
June 20	May 22	Mar. 28	Oct. 12	Nov. 14
June 25	May 27	Apr. 2	Oct. 17	Nov. 19
June 30	June 1	Apr. 7	Oct. 22	Nov. 24
July 5	June 6	Apr. 12	Oct. 27	Nov. 29
July 10	June 11	Apr. 17	Nov. 1	Dec. 4
July 15	June 16	Apr. 22	Nov. 6	Dec. 9
July 20	June 21	Apr. 27	Nov. 11	Dec. 14
July 25	June 26	May 2	Nov. 16	Dec. 19
July 30	July 1	May 7	Nov. 21	Dec. 24
Aug. 4	July 6	May 12	Nov. 26	Dec. 29
Aug. 9	July 11	May 17	Nov. 31	Jan. 3
Aug. 14	July 16	May 22	Dec. 6	Jan. 8
Aug. 19	July 21	May 27	Dec. 11	Jan. 13
Aug. 24	July 26	June 1	Dec. 16	Jan. 18
Aug. 29	July 31	June 6	Dec. 21	Jan. 23
Sept. 3	Aug. 5	June 11	Dec. 26	Jan. 28
Sept. 8	Aug. 10	June 16	Dec. 31	Feb. 2
Sept. 13	Aug. 15	June 21	Jan. 5	Feb. 7
Sept. 18	Aug. 20	June 26	Jan. 10	Feb. 12
Sept. 23	Aug. 25	July 1	Jan. 15	Feb. 17
Sept. 28	Aug. 30	July 6	Jan. 20	Feb. 22
Oct. 3	Sept. 4	July 11	Jan. 25	Feb. 27
Oct. 8	Sept. 9	July 16	Jan. 30	Mar. 4
Oct. 13	Sept. 14	July 21	Feb. 4	Mar. 9
Oct. 18	Sept. 19	July 26	Feb. 9	Mar. 14
Oct. 23	Sept. 24	July 31	Feb. 14	Mar. 19
Oct. 28	Sept. 29	Aug. 5	Feb. 19	Mar. 24
Nov. 2	Oct. 4	Aug. 10	Feb. 24	Mar. 29
Nov. 7	Oct. 9	Aug. 15	Mar. 1	Apr. 3
Nov. 12	Oct. 14	Aug. 20	Mar. 6	Apr. 8
Nov. 17	Oct. 19	Aug. 25	Mar. 11	Apr. 13
Nov. 22	Oct. 24	Aug. 30	Mar. 16	Apr. 18
Nov. 27	Oct. 29	Sept. 4	Mar. 21	Apr. 23
Dec. 2	Nov. 3	Sept. 9	Mar. 26	Apr. 28
Dec. 7	Nov. 8	Sept. 14	Mar. 31	May 3
Dec. 12	Nov. 13	Sept. 19	Apr. 5	May 8
Dec. 17	Nov. 18	Sept. 24	Apr. 10	May 13
Dec. 22	Nov. 23	Sept. 29	Apr. 15	May 18
Dec. 27	Nov. 28	Oct. 4	Apr. 20	May 23

CHAPTER VIII

PARTURITION

The period of parturition is one of the most critical stages in the life of any animal. All the advantages gained in selecting healthy parent stock and providing the very best of environmental and nutritional conditions through gestation can be dissipated at this time through carelessness or ignorance. Generally speaking, animals were more healthy and rugged in their wild state than they are now. They ate natural feeds and brought forth their young in the fields and glens. All these conditions tended toward a minimum of loss, so far as the state of nutrition and sanitation were concerned. Domestication has altered this, and under artificial conditions animals cannot reach maximum efficiency without man's help and assistance. Death itself takes a large toll during parturition, and in many other cases the handicap of joint ill, scours, etc. contracted at parturition, detracts to a marked degree from an animal's ultimate efficiency. The losses in most cases are due to ignorance of basic principles.

Place of Parturition.—Parturition, or the act of giving birth to young, is a matter of vital concern in the attempt to produce healthy, vigorous livestock. If conditions are normal and the season permits, by far the best place for mares or cows to drop their young is in a pasture, because the instinct of the mother in these classes of livestock is generally superior to man's judgment, and on pasture the animal is free to move about, is not rendered nervous through human presence, and the danger to the young from infection is practically *nil*. During this time ewes should be kept under fairly close surveillance in a lambing pen, and sows should be shut up by themselves in a house or pen. With proper thought and care the advantages gained, in all classes of livestock, from giving birth in the open can be duplicated in the maternity stall or pen with the distinct added advantage that assistance can be given if it be required.

Time of Parturition.—A very necessary condition for successful parturition is that the breeder know when to expect it, and this

predicates the keeping of a record of the breeding of all females. The record book, coupled with a knowledge of the normal gestation period and a sharp lookout for the unexpected, will enable the breeder to have things in readiness for the reception of the new-born. In some instances a knowledge of breeding dates and of gestation period is not enough to insure that everything shall be in readiness, but without this information the case is hopeless. If a stall or pen is to be used, and as the time for parturition approaches, the females should be watched with even more diligent care than usual. They should not at this time be subjected to sudden changes of any kind, in feed, exercise, or care. Moderate exercise is necessary to keep the muscles in good tone and to prepare them for the strain that lies ahead. The feed should be of a somewhat laxative nature—this point cannot be overstressed. The droppings must be watched closely and if, even in spite of proper selection of feeds, constipation does make its appearance it must, for the safety and wellbeing of both mother and offspring, be quickly overcome. Feeds indicated at this time are pasturage, silage, roots, legume hays, bran, linseed-oil meal, ground oats. In case of emergency, linseed oil or epsom salts may be administered. An abundance of good drinking water is also essential. When bred, animals should be in fairly thin condition, but they should be gaining and should continue to gain slowly all through the gestation period, coming to the time of parturition in good condition both as regards quality and amount of flesh. Extremes in thinness as well as fatness should be sedulously avoided. The females should be separated from the herd at least 5 to 10 days before parturition, so that danger of violent contact may be avoided. This will also enable the breeder to watch them more closely and will provide opportunity for the animal to become accustomed to the stall or pen where parturition is to occur. Animals are naturally more or less nervous at this time and it is necessary that everything possible be done to allay their fears, thus conducing to ease of parturition as well as to the safety of the new-born.

Sanitation.—All maternity stalls or pens should be built or arranged so that maximum advantage can be taken of the most efficient germicide and also of the most efficient growth promoter known, namely, sunshine. Besides admitting the greatest possible amount of sunshine, such stalls or pens should be planned so as to give the highest degree of safety to the dam and her

offspring and the greatest degree of convenience to the man in charge. Before putting any female into a maternity stall or pen, both the animal and the pen should be thoroughly cleansed with a disinfectant solution. The coal-tar disinfectants, such as cresol, are good for this purpose, a 2 per cent solution to be used on the animal and a 5 per cent solution on the stall. The young are quite apt to suck at various parts of the mother's body, therefore, her whole body, more particularly the teats, should be kept clean. The floor and walls should be scrubbed thoroughly, care being taken to work the material well into the cracks and corners. Fresh, clean bedding should be used, preferably straw or hay rather than sawdust or shavings, as either of the latter are quite apt to get into the stomach or lungs of the new-born and cause inflammation. For sows, the hay or straw must be short enough so that the pigs cannot burrow under it, thus becoming hidden from view and running the risk of being trampled to death. The sow's pen requires a guard rail placed about 8 inches from the wall and 8 inches high from the floor. Sows kept in cement-floored houses should have in one corner a plank platform with bedding on which to sleep.

Signs of Parturition.—Mares and cows will usually evidence a falling away or loosening of the ligaments in the rump region a day or two previous to dropping their young. They will also start "to make bag" and there will be a noticeable swelling of the vulva. Wax usually forms on the mare's teats a day or two before foaling. Most animals will give evidence of approaching parturition by their nervousness. Sows generally will be found picking up straw, sticks, etc. and making them into a nest. The bag of a ewe or sow will start to "make up" and often the young can be seen to move in the uterus. The characteristic labor pains set in a few hours previous to parturition.

Act of Parturition.—If everything is normal and the animal has been properly fed and cared for, the act of parturition can usually be accomplished without assistance. Under these conditions the best procedure for the manager or herdsman, after checking up and seeing that all details have been properly carried out, is to go on with his work and let nature take its course. Here again the happy medium between too much attention and too little should be the aim. Meddling is often dangerous alike to parent, offspring, and owner. On the other hand, the day of parturition is rather a poor one to choose for a holiday. Mere human pres-

ence at this time is often objected to by the animal, especially by mares, which are particularly sensitive to human presence and will delay foaling as long as possible if such persists. Other animals, though not so sensitive, also prefer seclusion at this time. An occasional visit to note progress of events is always desirable and often profitable, and at this time an invaluable asset is the animal's confidence in her caretaker.

During uterine life, the young lie on their backs in the uterus. At the end of gestation, increased muscular contractions occur in the uterus, bringing on the well-known phenomenon of labor pains.

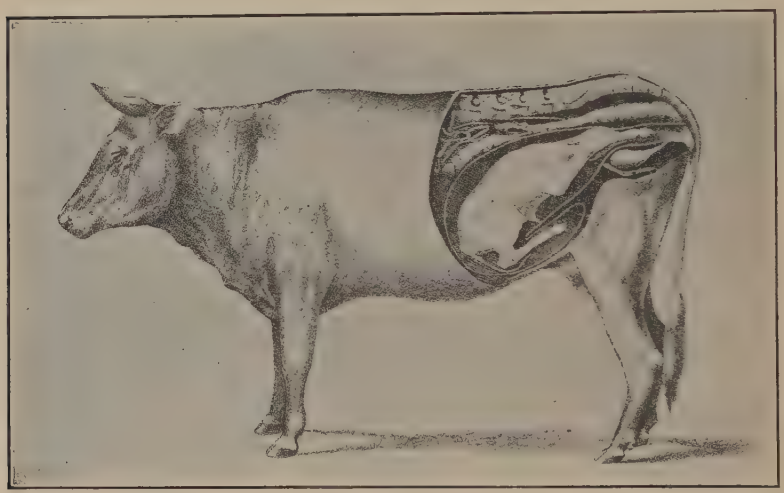


FIG. 33.—Normal position of calf in utero. (*From U. S. D. A. Diseases of Cattle.*)

The pains are caused by the contraction of the longitudinal muscles of the uterus, which in this way dilate the os or the neck of the uterus. "Even in the virgin the uterine muscles undergo very slight rhythmic contractions, as may be seen when the organ is withdrawn from the body and kept in salt solution at body temperature, and these contractions may be greatly increased by applying mechanical stimuli."[1] At other than the heat period, these contractions are very slight, only increasing to great intensity at time of parturition, at which time the muscles of the uterus are very greatly developed. At the onset of pains, the animal becomes restless, for which reason it should be in a roomy

[1] MARSHALL, F. H. A., Physiology of farm animals, p. 188, Cambridge University Press, 1920.

stall or pen, never in a stanchion, and there should be no protruding constructions on which she can injure herself. At this time, too, she is more or less feverish and the skin is hot and dry. The dilation of the os is soon followed by the contraction of all the uterine muscles, as well as the abdominal muscles and the diaphragm, the contractions being followed by a short period of calm for rest. The combined contractions of the uterine and abdominal muscle soon force out the fetal membranes, which contain fluids, these acting as an elastic wedge gradually to open the passages. After protrusion, the water bag soon breaks, releasing the fluid, and the young, which in the meantime have turned first onto their sides and then all the way over onto their stomachs, soon make their appearance. The two normal presentations are front feet first, with head resting on the knees, or hind feet first.

The immediate inciting causes of parturition are not well known. Various explanations have been attempted. Spiegelberg has suggested that the fetus secretes a substance which, finally entering the maternal blood, reaches the nerve centers and through them acts on the uterine nerves in the spinal cord. Beard and others have held that there is an intimate relation between the estrus cycle and parturition. It is known that abortion is more apt to occur at the time of the periodical return of heat. But may it not be true that the period of gestation is itself governed by a certain rhythmic law or periodicity similar to that which brings about the heat period? Other possible explanations are that the placenta begins to decay or atrophy at the end of a given period and thus loses its hold on the uterine walls, and the waste products thus developed may furnish the real stimulus which results in parturition. The death of the fetus prematurely will generally bring on expulsive movements of the uterus and speedily relieve the uterus of its dead burden.

It is probable that the causes of parturition are very complex and that a combination of the above, together with other causes, may bring about eventually the successful birth of the young mammal after the normal period of existence in the uterus.[1]

The normal process of parturition depends upon the integrity of the spinal cord, which coordinates the various muscular movements, but, as already mentioned, the uterus undergoes rhythmical contractions independently of its nerve connections, and will do so after separation from the body if maintained at the normal temperature and suspended in a suitable saline fluid. Goltz has shown that the bitch will give birth to pups after the complete exsection of the spinal cord in the lumbo-

[1] MUMFORD, F. B., The breeding of animals, pp 75–76. The Macmillan Company, 1917.

sacral region, and Simpson in an experiment on the sow in which the posterior spinal cord was destroyed showed that a litter of young pigs could be expelled by uterine action alone, except for the last pigling, which remained in the vagina, owing to the abdominal muscles not acting and there being no young ones in process of passing out from the uterus to propel the last pigling through the vaginal opening.[1]

The duration of parturition varies in different species of animals, being in the mare normally 5 to 15 minutes; in the cow ½ to 2 hours; in the ewe 15 minutes for each lamb born; and in the sow 10 to 30 minutes for each pig, with sometimes an interval up to an hour between the pigs.

The last stage of parturition consists of the expulsion of the fetal membranes or afterbirth. This may follow soon after birth, but if it is delayed more than 24 hours steps should be taken to remove it. When the afterbirth protrudes, its final expulsion may be somewhat hastened by tying to it a weight, such as half a brick. The treatment most usually recommended at the present time in case of retained afterbirth is the insertion of iodoform tablets into the uterus in order to prevent somewhat the danger from putrefaction, and also the daily douching with a normal salt solution. The manual separation of these membranes from the cotyledons is sometimes advisable. When expelled, the afterbirth should be removed at once and buried or burned and the animals not allowed to eat it. If, as sometimes happens, the young are born in the intact membranes, they should be liberated immediately in order to prevent asphyxiation.

Assistance at Parturition.—If, after reasonable time and effort have been expended, a female appears to be making no progress in parturition, it is advisable to make an examination so that proper assistance can be rendered before the animal has completely exhausted her strength in futile efforts at expulsion. For such an examination, the hand and arm should be thoroughly cleansed and lubricated and the finger nails cut short. After proper precaution has been taken against injury, the hand, fingers held in a cone shape, is inserted into the vagina. There may be various types of mal presentations, such as only one front leg with the other turned back; one hind leg and the other stretched forward; abdominal or sacral presentation; head turned back on the side; head protruding with fore legs retained; all four feet

[1] MARSHALL, F. H. A., Physiology of farm animals, pp. 189, 190, Cambridge University Press, 1920.

FIG. 34.—Abnormal positions of calf in utero. These must be corrected before parturition can take place. (*From U. S. D. A. Diseases of Cattle.*)

presented; etc. The cardinal features in the work of correcting the position of a fetus are cleanliness, quietness, gentleness, and perseverance. It is seldom necessary to resort to the knife at this time. If the presentation is normal, strength for expulsion merely being lacking, the feet can be grasped and a pull exerted downward and backward to conform to the shape of the pelvis and to the back of the young. The pull should only be exerted at the time the dam is in labor, never in the rest periods, except to maintain the gain that has been made. In correcting an abnormal presentation, it is often necessary to push the young well forward into the uterus and this should be done gently and during the rest period, not during the labor period. A small clean rope can be used to slip around the feet of a colt or calf and a piece of No. 9 wire with one end bent into a hook to catch under the lower jaw is often useful as a last resort with lambs or pigs.

Care of Young at Birth.—If birth is normal and the young are normal and vigorous, interference is not advisable. A colt or calf should be on its feet and sucking within an hour after birth, but if not, some assistance may be given so that the young animal can begin to get nourishment. The same also applies to lambs where, in case of twins, the shepherd generally removes the first lamb until parturition is complete, when both lambs are allowed to nurse. In the case of sows, it is essential for the herdsman to be present at parturition in order to remove the pigs when born, dry them, and put them in a safe place until parturition is complete, when all are allowed to nurse. Losses from various forms of sterility are severe enough without adding to them by negligence at time of parturition. Sometimes it is necessary to remove the young from the membranes so that they can start breathing, while on other occasions it is necessary for the same reason to remove mucus from the mouth and nostrils. Many animals apparently stillborn can be induced to start breathing by slapping the sides, working the front legs and chest, as in restoring a man who has been submerged in water, blowing into the nostrils, tickling nostrils with a feather, and so on. If an animal is stillborn, vigorous action on the part of the attendant will often cheat death, as will also protection from the elements for those which have safely arrived. With colts and calves, it is essential soon after birth and in order to prevent joint ill or scours to dip the stump of the umbilical cord into a solution of iodine kept in a wide-necked bottle. As previously mentioned, the dam should

be cleaned thoroughly before parturition and no discharges from the vulva be allowed to soil the teats, to be later swallowed by the young in nursing. Little pigs' teeth, be they black or any other color, should never be pulled out—in fact, they should never be touched until the sow gives evidence that the pigs are hurting her when nursing, in which contingency the sharp points of the teeth can be clipped off with a pair of small nippers. It is essential that the bowels of the young animal move fairly soon. To accomplish this nature provides colostrum, the first milk, which has a laxative effect. Even though the animals are to be weaned immediately, they should start life on their mother's milk, fed in a clean receptacle at body temperature and at regular intervals. If for any reason there is no milk from the mother, cow's milk can be substituted and a little castor oil administered in order to avoid the danger of constipation.

Overfeeding.—More young animals die from pampering and overfeeding than from neglect and starvation. To keep a young animal on feed and gaining steadily from the day of birth is an art, gained only through experience. Any young animals do best if fed regularly, often, and, last, but not least, moderately. They should clean up their feed with a relish and look for more, the secret of success being to keep them a little hungry. Misguided kindness in the form of too much feed must be persistently and consistently avoided.

Marking.—If animals are to be marked in any way, it should be done early and before there is any chance for making mistakes. Pigs are usually marked by notching the ears, for example, a notch in the outer side of right ear standing for 1, outer side left ear for 3, inner side of right ear for 10, and inner side of left ear for 30. Lambs and calves are best marked by metal tags or calves by tattooing. If the tattoo fades, it can be made permanent in the other ear at about two years of age.

Care of Mother at Birth.—After safely delivering her young, the things a female needs most are rest and quiet, together with a moderate amount of temperate water. She should not be fed for 12 to 24 hours after parturition and should be started on feed very gradually. Gruels of bran and ground oats with perhaps a little linseed-oil meal are good at this time, together with a small amount of good-quality leguminous hay and some pasturage. The feed must be moderate in amount for two reasons: (1) a return to the normal condition of the dam's system will be

hindered by overfeeding, and (2) the presence of too much milk in the udder as a result of overfeeding is sure to cause scouring in the young, which is always a serious drawback to normal health and growth. The wise herdsman never feeds a nursing female until he has observed the character of the droppings of the young, and at the first sign of scouring the dam's feed must be cut at least in half. Feed given to an animal suffering with a bacterial infection, such as scours, will not be properly digested and assimilated. Some calves may have already become infected in utero and may scour immediately after birth. All feed should be withheld from such animals for periods up to 72 hours and calf scour serum should be administered. Cows should not be milked out completely immediately after calving, as this is likely to bring on milk fever. It is necessary, however, to see that some milk is drawn from all the quarters, because if any of the quarters are left full of milk for too long a time they are apt to be injured. From 2 to 4 weeks should be allowed to get a female back to full feed. Mares can go back to light work in 2 weeks. Care must be exercised that the foal left in the stall cannot harm itself, because it will be quite restless without its dam. The foal should be allowed to nurse midmorning and midafternoon after the mare has been allowed to cool off, if warm, and after her udder has been washed.

Feeding Mother and Offspring.—If the young are ever to achieve to the maximum of their inherent capabilities, they must get started early along the proper path and must be kept moving. Normal healthy parents are the first prerequisite, clean maternity stalls the second, proper feeding and management of the lactating female the third. The young themselves will soon (2 to 3 weeks) evidence a desire to eat something besides milk. This desire should be satisfied not with shavings and sawdust but with good pasturage, fine-quality hay, and a suitable grain mixture, remembering that whole milk, and more especially skim milk, is very high in protein. Along with a suitable quantity and quality of milk from the dam and such other feeds as just mentioned should go a sufficient amount of exercise, preferably at pasture and in the sunshine. If worms are prevalent it will be necessary to remove all green growth from lamb and pig runs and to put the pigs and the lambs on fresh pastureage that has not had sheep or sows on it for at least 12 months. The greatest

drawbacks to the successful rearing of desirable young are overfeeding and underexercising.

Complications at Parturition.—The female is subject to many complications following parturition, *e.g.*, retained placenta, metritis, eversion of the uterus, rupture of the uterus or of the bladder, vaginitis, mamitis, etc., for any of which the breeder will do well *immediately* to enlist the services of a competent veterinarian.

CHAPTER IX

GENETICS

A study of individual similarities and differences makes up the science of genetics. There have been three milestones marking the progress of this still youthful science. The first was the establishment of the evolutionary theory which postulates that all forms of life have come from some preëxisting form and that the rise of new species has been due to *variation* and *selection*. Evolution therefore is racial "becoming," while genetics is individual "becoming," the same general principles underlying both. The other two milestones were, first, the development of cytology, or the science of the cell, and, second, Mendel's epochal work on the behavior of characteristics in transmission. Hooke noticed the cellular structure of cork in 1665 and discussed it in his writings and, though in itself it led to nothing of importance, this discovery is the historical introduction to the cell. It was not until 1838 that Schleiden and Schwann, two German scientists, propounded the cell theory or cell doctrine which postulated the cell as the unit of structure in both plant and animal kingdoms. This discovery of the physical make-up of living things was significant, but there was a period of more or less barren years and most of our knowledge of the complicated workings of cells has come since 1870. In like manner, Mendel's epochal discovery, in 1865, of the behavior of hereditary units bore no fruit until its rediscovery in 1900 by three investigators working independently.

Content of Genetics.—Bateson coined the term Genetics, which from its derivation from the Greek root ΓΕΝ, to become, literally means the beginning, or the coming into being of organic life. Genetics, however, does not stop with parturition or birth, but rather it expresses the idea of the full becoming of the individuality of the organism. This point should be borne in mind constantly by the student. Broadly speaking, genetics is the study of the why and wherefore of individuality. It is obvious that the individual will either be like its parents or different from them. What genetics attempts to do is to systematize

knowledge regarding these similarities and differences and to furnish a rational explanation for them.

There is an old deep-rooted belief to the effect that "like begets like." Experience teaches that sows bring forth pigs not calves, and in this sense "like begets like," but when the attempt is made to apply the idea in minute details to parent and offspring, difficulties are encountered. While there may be, and generally is, a greater or less degree of similarity between the two, the expectation that parent and offspring may be exactly alike causes many a disappointment. The fact of the continuity of the germplasm would lead one to expect that offspring would resemble their parents to a greater or less degree, and this, in truth, is just what observation teaches. Any organism receives the determiners for all its characteristics from its ancestors through its immediate parents. It is inconceivable that they could come from any other source and there is no evidence that any characteristics can be exhibited in opposition to the hereditary determiners.

The sum total of all the possibilities and accomplishments of an organism is its individuality. This may appear as the expression of characteristics exactly similar to those exhibited by any of its ancestors, a blend or a mosaic of ancestral characteristics, or one or many entirely new characteristics due to the interaction of ancestral determiners. Strictly speaking then, it may be seen that an organism's individuality is the sum total of all its characteristics which result from the union of germ cells produced by its particular parents. Genetics is the science dealing with individuality, which, in turn, consists of ancestral similarities and differences.

The reappearance of ancestral traits in offspring is known as *heredity* and, of necessity, must be germinal. The expression of modified or new characteristics in offspring is known as *variation*, which, as will be seen later, may be of two sorts, either germinal or somatic. Heredity and variation are the phenomena which make up the content of genetics or an organism's individual becoming. This terminology will be adhered to throughout the work, "heredity" being used in the limited sense as referring to similarities (except where impossible because of quotations). In outline form this distinction may be shown as follows:

Genetics { Heredity / Variation } Or, expressed in other terms, Inheritance { Similarities / Differences }

Environment and Education.—Thus far particular stress has been laid upon the complement of ancestral determiners, or upon an animal's inheritance. The student will here be reminded of two other influences which aid in shaping individuality, namely, environment and training. Any individuality is a product of the interaction of these three influences and, while resting on the complement of ancestral determiners as its base, this does not in any way minimize the influence of the other two. Many variations are no doubt due to environmental causes. The complement of ancestral determiners, however, does set the upper limit which an organism can reach. It is a breeder's province, therefore, to select breeding animals which will set a high upper limit and then so to modify environment and training that that limit may at least be approximated.

FIG. 35.—A scrub cow before and after being subjected to a good environment. Besides the increase in condition evidenced in the pictures she increased in production 2,814.6 pounds of milk and 113.75 pounds of fat. (*Photo from Iowa Ex. Sta. Bull.* 188.)

Problems of Genetics.—The problem of genetics is essentially a threefold one. In the final analysis what is sought through genetics is the physico-chemical cause, the mechanism of transmission, and the hereditary specificity that bring about similarities or differences in the fully developed individual when compared with its forbears. It is impossible to imagine the extent to which the discovery of these facts will enrich mankind, and it would seem that these discoveries may overshadow the remainder of man's discoveries about the universe and himself. The problem is a complicated one and knowledge from many sources will no doubt eventually flood it with understanding. The methods of research applicable to the three main phases of the problems of genetics will now be indicated.

Problem of Physico-chemical Cause.—An elaboration of the physico-chemical entities that must function in the transmission of

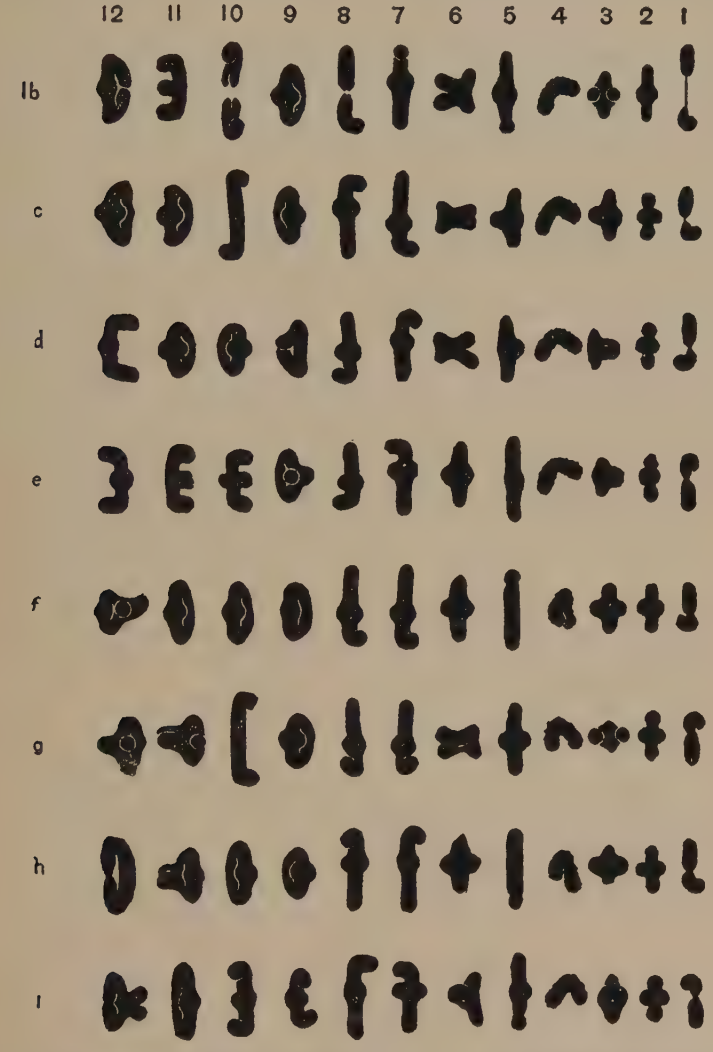


FIG. 36.—Eight chromosome groups of twelve chromosomes each of *Trimerotropis*. (*From Morgan after Carothers, Physical Basis of Heredity, J. B. Lippincott Co.*)

similarities or the rise of differences belongs in the field of cytology. Much progress has already been made here and it is through the

knowledge of chromosomes that the foundation for present-day genetics has been laid. Research has established the fact that the behavior of the chromosomes in gametogenesis exactly fits the observed appearance and distribution of characters in the developed individual. This is an accomplishment of the greatest moment. There can be little doubt but that the chromosomes constitute the "bridge of inheritance." The function of the cytoplasm of the cell is not to be overlooked, but it seems to be no more than secondary to the nuclear material contained in the chromosomes. In the case of certain plants there is genetic evidence which seems to indicate that the chlorophyll characteristics of these plants are controlled by plastids which are distributed in a more or less haphazard fashion to the daughter cells, but "there is no contradiction here in any sense to Mendelian inheritance, but only an additional type of inheritance."[1]

The method of cytology has its limitations and dangers. In the first place, cytology as a method of attack has been weak because it has been observational rather than experimental. Some progress has been made in the experimental field which confirms the chromosomal doctrine, though much more work is needed. True, the direct proof that a certain gene or chromomere gives rise to a certain somatic characteristic is probably lacking, but the relation between cytological phenomena and somatic differences is so clear, especially in the case of sex-linked characters, that such a conclusion can hardly be escaped.

The dangers lurking in this field are those of misinterpreting the results of staining and of postulating a variety of interpretations for the same facts. Pearl has pointed out the further danger of building up hypotheses that are capable of numerical expression to fit new facts because such hypotheses "always somewhere involve a statement or implication as to the qualitative cause of the quantitive phenomena observed." If after calculation the numerical results approach "expectations" and "the agreement is good, the investigator is likely, and here lies the fallacy, to draw the conclusion that this agreement proves that the qualitative assumptions made in the hypothesis are correct. Of course, the agreement logically proves nothing of the sort."[2]

[1] Morgan, T. H., Physical basis of heredity, p. 223, J. B. Lippincott Company, 1919.

[2] Pearl, R., Modes of research in genetics p. 29, The Macmillan Company, 1915.

The most important progress which has been made within the last decade in genetic science has been that of interpreting Mendelian phenomena of inheritance in terms of the behavior of the cell mechanism. Thus far this work has been carried to any degree of completeness in only one species, the common fruitfly, *Drosophila ampelophila*. In the extensive investigations which have been made with this species, Morgan and his associates have demonstrated how close a correlation exists all along the line between cell behavior and hereditary distribution of characters. Certain characters are distributed independently of each other, the pairs of chromosomes separate independently of each other in the formation of gametes; certain characters display irregularities in distribution and expression associated with differences in sex, the chromosome content of the two sexes is demonstrably different; four sets of characters exist the members of which tend to remain together in transmission in the combinations in which they occurred originally, the entire chromatin material is contained in four pairs of chromosomes; and finally irregularities in character distribution have been discovered, the chromosome constitution and distribution in such cases are correspondingly irregular. These facts the student will be better fitted to appreciate later on; they are given here to show how the results of one method of investigation are supported and strengthened by those of other methods.[1]

In the present state of knowledge it is perhaps futile to speculate regarding the chemical make-up and the physical relationships holding in germplasm and somatoplasm. No doubt there are many intricate processes at work. Whether the genes are enzymes or proteins or both is not known. In speaking of this phase of the problem Morgan says:

It seems to me, therefore, that it is both premature and highly speculative at present to tie up the genetic evidence concerning the genes with hypotheses concerning their chemical composition. I urge this, but at the same time I realize, of course, that we should endeavor to obtain as soon as possible better knowledge as to the chemical nature of the chromatin.

Walter quotes Wilson as follows:

The essential conclusion that is indicated by cytological study of the nuclear substance is that it is an aggregate of many different chemical components which do not constitute a mere mechanical mixture, but a complex organic system, and which undergo perfectly ordered processes of segregation and distribution in the cycle of cell life. That these

[1] Babcock and Clausen, Genetics in relation to agriculture, p. 9, McGraw-Hill Book Company, Inc., 1918.

substances play some definite rôle in determination is not mere assumption, but a conclusion based upon direct cytological experiment and one that finds support in the results of modern chemical research . . .

In my view studies in this field are at the present time most likely to be advanced by adopting the comparatively simple hypothesis that the nuclear substances are actual factors of reaction by virtue of their specific chemical properties; and I think that it has already helped us to gain a clearer view of some of the most puzzling problems of genetics.[1]

Problem of Mode of Transmission.—There are two methods of studying the manner in which characteristics are transmitted from one generation to the next. They are (1) by studying the ancestors of certain individuals or (2) by studying the progeny of certain individuals. The former, or ancestor study, may be carried on by means of biometry or by means of data recorded in purebred herd books. The progeny study is the experimental or Mendelian method, in which the matings are planned and the study has a statistical basis. Inquiry will now be made into these methods of genetic research, bearing in mind that in this field, particularly, environmental conditions must be carefully controlled so that the observed results may justly be attributed to the make-up of the germplasm.

The statistical method of attacking the problem was originated by Sir Francis Galton, later developed by Karl Pearson, and is known today as biometry. It is a most useful tool in the hands of the analytical geneticist. Its function is to measure the degree of resemblance between related individuals and to express the result in numbers. With the aid of biometry Galton postulated his Law of Ancestral Inheritance, which states that on the average each parent contributes one-quarter, each grandparent one-eighth, and so on of the individual's total inheritance, which equals 1.0. As pointed out by Pearl, the weakness of the method as a means of research lies in two facts: (1) that it is largely a method of description and does not attempt to give the cause of the events, and (2) that since biometry gives the degree of resemblance between parent and offspring and since heredity is a cause of the resemblance, therefore the biometrical method (correlation) measures the degree or intensity of inheritance. As Pearl points out, heredity is *not* the sole cause which can lead statistically to a significant correlation between parent and offspring. "Anything whatsoever which tends to bring about local group

[1] WALTER, H. E., Genetics, pp. 34–35, The Macmillan Company, 1919.

differentiation within the sample included in the table will tend to produce the same result, altogether independent of any genetic relationship or the absence of it."

With its limitations and dangers kept in mind, biometry, properly used, is a valuable agent in the study of genetics.

Herd books and Advanced Registers of dairy cattle contain a wealth of material which may shed light on the problems of genetics. With the aid of such records the manner of transmission of superficial characters, such as color marking, set of ears, and so on, as well as the deeper lying functional activities, such as speed, milk production, and so on, may be investigated. This method can also be criticized as being descriptive rather than experimental, and in it there is also the danger that an investigator may take half the facts and support any case. These records are now beginning to yield information which should prove of great value to practical breeders by explaining how certain traits are inherited and possibly also by showing the falsity of time-worn beliefs.

The two preceding methods have dealt with the ancestors. The following will be concerned with progeny. This is the experimental-breeding or pedigree-culture method, of which Mendel was the founder. He succeeded in establishing the basic plan of hereditary transmission because he reduced his problem to its simplest form and studied one pair of contrasted characters at a time. Like the Galtonian, this method is also statistical. In general, it consists of producing pure races, crossing them, mating the hybrids, and ascertaining the ratios in the F_2 and later generations. The other results of this method have been Johannsen's pure-line theory and de Vries's mutation theory. The former of these has been defined as "all the progeny of a single self-fertilized individual." Such individuals give rise to fluctuating variations, but these variations are probably due to environmental conditions and not to germinal variations. In other words, this points to the static character of the germplasm. The mutation theory of de Vries, on the other hand, which postulates sudden heritable changes in the germplasm, is a "directly contradictory theory in its fundamental postulate; but the very great infrequency with which changes occur in germinal elements saves the pure-line theory from inutility."

The experimental-breeding method with all its accomplishments can be criticized because it deals with what genes or chro-

momeres do, not what they are. In the field of animal breeding, however, the information that the experimental method can yield, especially through crossbreeding experiments, is very much to be desired and should prove to be of very great worth.

Problem of Hereditary Specificity.—The third great problem of genetics, following those of the physico-chemical cause of similarities and differences, and their mode of transmission, is that of hereditary specificity in the development of the individual. In other words, what is the mechanism resident in the fertilized ovum "which impels it to follow in each case a definite line of development?" This problem, unlike the other two, which dealt with the germplasm, is concerned with the somatoplasm. The method of attack here is the embryological one—not, to be sure, the old descriptive embryology with its manifest limitations in this respect, but the new experimental embryology, "using the term in its widest sense to include the study of such phenomena as regeneration, regulation, growth, etc." This is primarily a study of ontogeny and it will serve as a connecting link between the original zygote with its content of hereditary determiners and the fully developed adult exhibiting the characteristics for which determiners were present in the zygote.

Already, as Jennings has pointed out, the main features of the process of development are clearly indicated; the hereditary elements of the chromosomes remain the same in each cell; the reactions and functions of any cell depend upon this chromatin system working in conjunction with the cytoplasmic matrix in which it is located. From this fact may be drawn the broad conclusion that differentiation within the individual depends upon cytoplasm differentiation. The difficulty of the question of how and why should not deter investigation.[1]

Prerequisites for Genetics.—Babcock and Clausen discuss this question as follows:

Since genetics is a biological science, intelligent study of it presupposes a thorough grounding in general biology such as is given in foundation courses in botany and in zoölogy. Inasmuch as practically all domesticated plants and animals belong to the higher orders, particular attention should be given to the cycles of development in these organisms, especially those phases which are comprised in development and reproduction.

[1] Babcock and Clausen, Genetics in relation to agriculture, p. 10, McGraw-Hill Book Company, Inc., 1918.

Of particular importance is a general knowledge of physiology, not so much on account of the direct utility which it has in the study of genetics as for the attitude towards life phenomena which it awakens in the student. Genetics, indeed, is essentially a subdivision of physiology in the broader sense. A knowledge of mathematics is a valuable asset, because it is often necessary to subject the data of heredity and variation to mathematical treatment in order to interpret them properly. For the elementary study of genetics, a knowledge of the methods of dealing with simpler algebraic problems is sufficient; for advanced study a knowledge of the differential and integral calculus is highly advantageous. Finally, it may not be out of place to mention the fact that investigation in genetics is not confined to those who employ the English language. A reading knowledge of French and German is practically necessary for those who desire to pursue the subject very far.[1]

Prerequisites for the Scientific Breeder.—The above essentials for the geneticist, as pointed out by Babcock and Clausen, are fundamental as far as a scientific animal breeder is concerned. This individual is to be a composite of geneticist, physiologist, and practician, and the union of the three into one individual is necessary to produce a scientific animal breeder. In addition to general biology, general physiology, mathematics, and foreign languages, which are prerequisites for the geneticist, a thorough grounding in reproductive physiology is also necessary for a scientific animal breeder. This is essential for two reasons —first, that cytological phenomena may be coördinated in the proper manner with reproductive anatomy and physiology, and, second, that the animals may be given intelligent first aid when necessary and the veterinarian's point of view be understood. Veterinarians often fail because of lack of understanding and coöperation from owners. As a practician, a knowledge of types and breeds of animals and both extensive and intensive knowledge of his particular breed from its earliest inception up to and including the present are essential. To select and mate wisely is the work of a student of animal form and function. Finally, full development of characteristics inherent in individuals calls for efficient feeding, which in reality is based upon plant and animal chemistry. The above lists of prerequisites are formidable, no doubt, but a successful animal breeder has a complex task to perform and this demands thorough preparation, espe-

[1] Babcock and Clausen, Genetics in relation to agriculture, pp. 10–11, McGraw-Hill Book Company, Inc., 1918.

cially in fundamentals for as Emerson has said, "The height of the pinnacle is determined by the breadth of the base."

Genetics and the Practice of Breeding.—The practice of breeding is older than history. Its method is selection and its accomplishments legion. It has produced fast, fancy, and farm horses; increased the yield of milk from 100 or 200 to 37,000 pounds annually; and has produced the food which has enabled man literally to conquer his world. Genetics acknowledges gladly the achievements of empiricism and seeks the reason "why." The method of practical breeders has always been that of trial and error, and of necessity there has always been a goodly share of the latter. The greatest service that genetics can render to the practice of breeding lies in its ability to analyze and to provide logical explanations. This will inevitably result in the sifting of the true from the false, a service of no mean value, and one which is being fulfilled rapidly. If genetics did no more than unearth the principles underlying breeding and post "no-passing" signs at the head of all the blind alleys, it would expedite successful breeding to a marked degree. It is the hope, however, that through the study of genetics new methods will be devised which will lead even more quickly and surely toward the goal of more beautiful form and more efficient function. The mode of inheritance of most of the characteristics exhibited by higher animals is still unknown and from the very nature of the problem is difficult, though genetics bids fair to furnish the solution. When this has come about and the principles are thoroughly understood, genetics will have proved itself merely the handmaid of animal breeding, to which it will have rendered a valuable service in successfully and firmly fitting into place the keystone of all breeding operations, "rational selection."

CHAPTER X

MENDELISM

Gregor Mendel, an Austrian monk, was the first geneticist. There had been other great plant hybridizers before Mendel, but he was the first to attack the problem on a large enough scale and in such a thoroughgoing way that it became possible to determine the number of different forms under which the offspring

FIG. 37.—Gregor Mendel, the discoverer of the laws underlying inheritance.

of hybrids might appear, to arrange these forms with certainty according to their separate generations, and to ascertain definitely their statistical relations. In 1865 he published a report of 8 years' hybridization experiments, though 35 years elapsed before the validity of his pioneer work was established. Mendel, like many other men who have thought ahead of their time, died before the results of his splendid pioneering were appreciated. Like many other phenomena, this matter of inheritance proves to be quite simple in interpretation, and Mendel's success was

due in large measure to the fact that he reduced his problem to its very simplest form by studying one pair of contrasted characters at a time, coupled with the fact that he was dealing with factors carried in different chromosomes which therefore assorted independently. Mendel's work was duplicated in 1900 by three scientists, Correns, von Tschermak, and de Vries, leading to the rediscovery of Mendel's original work.

Content of Mendelism.—Mendelism postulates that determiners of characteristics behave in an orderly manner in inheritance, and that they can be studied and expressed statistically. Mendel's work established three general laws, namely, those of unit characters, dominance, and segregation. To these have been added since 1900 the following, namely, linkage, crossing over, linear order, interference, and limitation of the linkage groups. Some of these later principles are opposed to the original Mendelian principle of independent assortment, but for the sake of clarity and unity all the phenomena of inheritance, based on the *unit-factor* idea, are known under the collective term *Mendelism.*

Mendelian Terms.—The following terms are now in general use in referring to Mendelian phenomena.

Unit characters—any characters of any organism that behave as a unit in inheritance; eye color in man, horns in cattle, etc.

Unit factor—the particular factor or gene in the chromosome that brings about the development of the particular characteristics in the organism.

Allelomorph—a factor, located in a corresponding locus of the homologous chromosome, that conditions the development of a contrasted character.

Phenotype—what an organism looks like, *e.g.*, if, in peas, factors for both the tall and the dwarf characteristics (*T* and *t*) are present, the pea grows tall, and therefore belongs to the tall phenotype.

Genotype—what an organism actually is as determined by its germplasm, *e.g.*, *TT* and *Tt* are both tall peas, therefore the same phenotype, but because of their different genotypic constitutions they belong to different genotypes.

Homozygous—a term describing an individual each of whose parents has contributed the same factor, *i.e.*, *TT* or *tt.*

Heterozygous—a term describing an individual each of whose parents has contributed different factors, *i.e.*, *T* and *t.*

P refers to the parent generation.

F_1 refers to the first filial generation.

F_2 refers to the second filial generation, etc.

Dominant—a term describing the factor that is able to manifest itself in the fully developed individual. In peas the tall factor is dominant over the dwarf.

Recessive—a term describing the factor that is unable to manifest itself in the fully developed individual. In peas the dwarf factor is recessive to the one for tallness.

Hybrid—the individual that arises from crossing parents that are pure for certain different characteristics. Crossing tall (*TT*) on dwarf (*tt*) peas produces a hybrid (*Tt*).

The Essence of Mendelism.—The Mendelian ratio in F_2 is three dominant to one recessive. Mendel crossed tall and dwarf peas and found all the offspring to be tall, because tall is dominant to dwarf. When these F_1 hybrids were crossed, the resulting F_2 generation consisted of tall peas and dwarf peas in the ratio of 3:1. The following diagram should make this clear:

TT — *tt*

Pure tall parent — Pure dwarf parent

T — *t*

Pollen after reduction — Ovule after reduction

Tt F_1 hybrid (tall)

T *t* Pollen of hybrid after reduction

{either ovule fertilized by either pollen.}

T *t* Ovules of hybrid after reduction

TT	*Tt*	*Tt*	*tt*
tall	:		dwarf
3			1

The *TT* peas are pure for tallness and can never produce anything but tall offspring. The same holds true for the *it* peas in respect to dwarfness. The two *Tt* peas are phenotypically tall, but carry the factor for dwarfness *t* as a recessive. Two of these crossed would again give:

T *t*

T *t*

TT *Tt* *Tt* *tt*, and so on *ad infinitum*.

This was the gist of Mendel's work, namely, that, starting with parents pure for some contrasted character, hybrids would be produced in F_1 that looked like the dominant parent; and in F_2 one individual pure for one grandparental characteristic, one pure for the other grandparental characteristic, and two hybrids carrying both factors and resembling the dominant parent, there being thus, in F_2, three dominants to one recessive.

Mendel's Work.—It is of importance to know in how far Mendel's results and later experiments meet mathematical expectation. For this reason it will be well to consider both Mendel's original work and some later experiments. The point at issue is whether Mendel discovered an interesting restricted phenomenon in peas or a universal law of inheritance.

Mendel secured some thirty-four more or less distinct varieties of peas and before beginning his own experiments subjected them to a 2-year trial to ascertain whether or not they would breed true to type. Knowing that the common characters of two plants are transmitted unchanged to the hybrids and their progeny and that each pair of contrasting characters of two plants unite in the hybrid in which the dominant character only is manifested, and that this dominant character is variable in the progeny of the hybrid, Mendel's experiment was planned to observe these latter variations in the case of each pair of differentiating characters and to deduce the law according to which they appear in the successive generations.

Mendel selected the following seven pairs of contrasted characters for study:

1. The difference in the form of the ripe seeds. These are either round or roundish,[1] the depressions, if any, occur on the surface, being always only shallow; or they are irregularly angular and deeply wrinkled.

2. The difference in the colour of the cotyledons. The albumen of the ripe seeds is either pale yellow, bright yellow, and orange coloured, or it possesses a more or less intense green tint.

3. The difference in the colour of the seed coat. This is either white, with which character white flowers are constantly correlated; or it is grey, grey brown, leather brown, with or without violet spotting, in which case the colour of the standards is violet, that of the wings purple, and the stem of the axils of the leaves is of a reddish tint. The grey seed coats become dark brown in boiling water.

[1] In each case the dominant character is underscored.

4. The difference in the form of the ripe pods. These are either simply inflated, not contracted in places; or they are deeply constricted between the seeds and more or less wrinkled.

5. The difference in the colour of the unripe pods. They are either light to dark green, or vividly yellow, in which colouring the stalks, leaf veins, and calyx participate.

6. The difference in the position of the flowers. They are either axial, that is, distributed along the main stem; or they are terminal, that is, bunched at the top of the stem and arranged almost in a false umbel; in this case the upper part of the stem is more or less widened in section.

7. The difference in the length of the stem. The length of the stem is very various in some forms; it is, however, a constant character for each, in so far that healthy plants, grown in the same soil, are only subject to unimportant variations in this character.

In experiments with this character, in order to be able to discriminate with certainty, the long axis of 6 to 7 feet was always crossed with the short one of ¾ to 1½ feet.[1]

The Mendelian Ratio.—The results of segregation in F_2 in those seven series of experiments by Mendel follow:

TABLE XII.—SUMMARY OF MENDEL'S EXPERIMENTS WITH PEAS

Number	Character contrast	Number in F_2	Dominants	Recessives	Ratio
1	Form of seed	7,324	5,474	1,850	2.96:1.00
2	Color of cotyledons	8,023	6,022	2,001	3.01:1.00
3	Color of seed coats	929	705	224	3.15:1.00
4	Form of pod	1,181	882	299	2.95:1.00
5	Color of pod	580	428	152	2.82:1.00
6	Position of flowers	858	651	207	3.14:1.00
7	Length of stem	1,064	787	277	2.84:1.00
Totals		19,959	14,949	5,010	2.99:1.00

Mendel was dealing with strictly contrasting characters and got no transitional or blending forms. The matter of personal bias was therefore obviated. The ratio which Mendel secured in F_2 with each pair of contrasted characters was in no case significantly different from 3:1. Many other investigations of single contrasting characters have yielded a similar 3:1 ratio. This

[1] CASTLE, W. E., Genetics and eugenics, p. 285, Harvard University Press, 1916.

is the established and accepted ratio for one pair of contrasting characters in the F_2 generation.

Mendel carried some of the descendants of the above hybrids along through four to seven generations and reports that "no departure from the rule has been perceptible."

He also made crosses of individuals differing in two and in three characteristics and found the same underlying principle active, namely, that the F_1 hybrids looked like the sum of the dominant characters put in by both parents and in F_2 all the characteristics were recombined into all the possible combinations.

The Mendelian Theory of Inheritance.—The essence of the Mendelian principles is summed up in this statement of Mendel's:

> The results of the previously described experiments led to further experiments, the results of which appear fitted to afford some conclusions as regards the composition of the egg and pollen cells of hybrids. An important clue is afforded in Pisum by the circumstance that among the progeny of the hybrids constant forms appear, and that this occurs, too, in respect of all combinations of the associated characters. So far as experience goes, we find it in every case confirmed that constant progeny can only be formed when the egg cells and the fertilizing pollen are of like character, so that both are provided with the material for creating quite similar individuals, as is the case with the normal fertilization of pure species. We must therefore regard it as certain that exactly similar factors must be at work also in the production of the constant forms in the hybrid plants. Since the various constant forms are produced in one plant, or even in one flower of a plant, the conclusion appears logical that in the ovaries of the hybrids there are formed as many sorts of egg cells, and in the anthers as many sorts of pollen cells, as there are possible constant combination forms, and that these egg and pollen cells agree in their internal composition with those of the separate forms.
>
> In point of fact, it is possible to demonstrate theoretically that this hypothesis would fully suffice to account for the development of the hybrids in the separate generations, if we might at the same time assume that the various kinds of egg and pollen cells were formed in the hybrids on the average in equal numbers.[1]

The Mendelian Principles of Inheritance. 1. *Unit Characters.* Although functioning as a simple entity, from the standpoint of inheritance an organism should be considered as being made up

[1] CASTLE, W. E., Genetics and eugenics, 300 pp., Harvard University Press, 1916.

of a large number of independent, heritable unit characters, though probably many rather than one factor or gene function in developing each unit character. The tall and dwarf peas demonstrate this principle.

2. *Dominance.*—Certain factors in the germplasm dominate others during development of the individual, thus determining its apparent characteristics, in other words, its phenotype. The recessive factor is unable to manifest itself in the presence of the dominant factor but may be carried along for many generations, to appear when it finds itself with a like recessive factor, *i.e.*, the dominant factor being absent. The cross of tall and dwarf peas illustrates dominance. The red calf, in the Angus breed, appears when two recessive factors for red come together, no dominant factor, black, being present.

3. *Segregation.*—The factors or genes carried in the chromosomes of both parents come together at fertilization and produce a new individual. Each parent has contributed a complete set of factors, some of which may be dominant, others recessive. When this new individual matures and begins to produce germ cells, the latter will go through the process of reduction, at which time the factors put in by the parents segregate or separate out from each other, one member of each pair going to each of the secondary germ cells. This principle is also illustrated in the tall- and dwarf-pea cross, the pollen or ovules produced in the F_1 hybrid carrying either the factor for tall or the factor for dwarf. These constitute the three original Mendelian principles and they are sufficient to account for all the phenomena known as independent Mendelian inheritance. For this independent distribution, the pairs of characters considered must be determined by factors carried in different chromosomes. If the two or more pairs of contrasted characters are determined by factors carried in the same chromosome, they would not be expected to assort independently, but rather to remain linked together. Linkage relations will be discussed later.

Monohybrid.—A cross involving only one pair of contrasted characters is termed a *monohybrid.* For its explanation it is assumed that at a certain locus in each of a pair of homologous chromosomes there are located factors, in one parent for tallness, and in the other for dwarfness. When each parent produces germ cells, pollen or ovules, the chromosomes of these cells go through the process of reduction, one member of each pair of homologous

chromosomes going to each of the secondary germ cells so that each germ cell produced has one-half the normal number of chromosomes. Therefore all the germ cells of one parent will contain the factor for tallness and all the germ cells of the other parent will contain the factor for dwarfness. At fertilization these chromosomes come together so that the normal number is again restored, and the individual grows tall because tall is dominant to dwarf, the latter factor being carried along as a recessive which may under proper conditions be able to manifest itself in some future generation.

Polled and horned cattle might be substituted for tall and dwarf peas and the problem worked out in the same way, the polled being dominant to the horned condition.

Dihybrid.—A cross involving two pairs of contrasted characters is termed a *dihybrid,* and, provided these factors are located in different chromosomes, independent assortment will result. For instance, Castle crossed a smooth, black guinea pig on a rough, white guinea pig, the resulting progeny in F_1 all being rough and black, the rough coat being dominant to smooth and black coat to white.

rC		*Rc*
Smooth black		Rough white
	RrCc	F_1 rough black

When two of these F_1 hybrids produce germ cells, spermatozoa or ova as the case may be, each germ cell will have the factor either for roughness or for smoothness, *R* or *r*, and the factor either for black coat or for white coat, *C* or *c*, because, being located in different chromosomes, the two pairs assort independently. All the possible combinations would be expected, therefore, of the four characters represented in the hybrid both in the spermatozoa produced by a male as well as the ova produced by a female.

Sperms	Ova *RC*	*Rc*	*rC*	*rc*
RC	*RR CC*	*RR Cc*	*Rr CC*	*Rr Cc*
Rc	*RR Cc*	*RR cc*	*Rr Cc*	*Rr cc*
rC	*Rr CC*	*Rr Cc*	*rr CC*	*rr Cc*
rc	*Rr Cc*	*Rr cc*	*rr Cc*	*rr cc*

Fig. 38.—Checkerboard of F_2 cross of smooth black × rough white guinea pig.

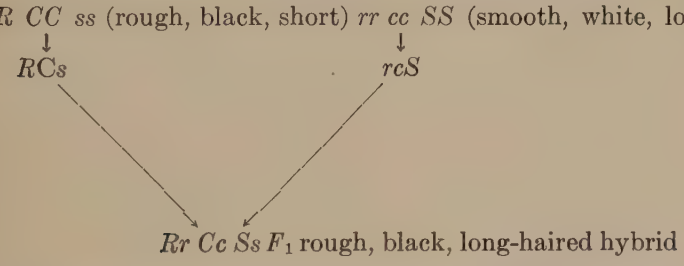
In the above checkerboard the presence of at least one large *R* determines roughness, at least one large *C* determines blackness, otherwise the animal will be smooth and white. Segregation is an extremely important feature of Mendelism, because through it something entirely new may be created. Starting with smooth, black and rough-white guinea pigs, a smooth white individual was created.

Checking up, the following results are seen to have been secured:

9 rough blacks.
3 rough whites.
3 smooth blacks.
1 smooth white.

The Mendelian ratio of 3:1 is, therefore, still intact, there being in F_2 twelve roughs to four smooths and twelve blacks to four whites.

Trihybrid.—A cross involving three pairs of contrasted characters is termed a *trihybrid.* For instance, a rough, black, short-haired guinea pig might be crossed on a smooth, white, long-haired guinea pig. Representing the dominant characters with capitals and the recessives with small letters, the genetic constitution of the two guinea pigs (for the characters immediately concerned) and the resulting hybrid would be as follows:



From this hybrid are gotten spermatozoa or ova of the following constitutions, each one, of necessity, carrying a factor for type, color, and length of coat:

RCS, RCs, RcS, Rcs, rCS, rCs, rcS, rcs

Chance meeting of spermatozoa and ova would give sixty-four individuals in F_2 and they would be rough if at least one large *R* were present, black if at least one large *C* were present, and short haired if at least one large *S* were present.

Or in cattle, if a polled, black-faced, black-bodied Angus is crossed on a horned, white-faced, red-bodied Hereford (again

Ova	Spermatozoa								
	PWB	*PWb*	*PwB*	*Pwb*	*pWB*	*pWb*	*pwB*	*pwb*
PWB	*PP WW BB*	*PP WW Bb*	*PP Ww BB*	*PP Ww Bb*	*Pp WW BB*	*Pp WW Bb*	*Pp Ww BB*	*Pp Ww Bb*
PWb	*PP WW Bb*	*PP WW bb*	*PP Ww Bb*	*PP Ww bb*	*Pp WW Bb*	*Pp WW bb*	*Pp Ww Bb*	*Pp Ww bb*
PwB	*PP Ww BB*	*PP Ww Bb*	*PP ww BB*	*PP ww Bb*	*Pp Ww BB*	*Pp Ww Bb*	*Pp ww BB*	*Pp ww Bb*
Pwb	*PP Ww Bb*	*PP Ww bb*	*PP ww Bb*	*PP ww bb*	*Pp Ww Bb*	*Pp Ww bb*	*Pp ww Bb*	*Pp ww bb*
pWB	*Pp WW BB*	*Pp WW Bb*	*Pp Ww BB*	*Pp Ww Bb*	*pp WW BB*	*pp WW Bb*	*pp Ww BB*	*pp Ww Bb*
pWb	*Pp WW Bb*	*Pp WW bb*	*Pp Ww Bb*	*Pp Ww bb*	*pp WW Bb*	*pp WW bb*	*pp Ww Bb*	*pp Ww bb*
pwB	*Pp Ww BB*	*Pp Ww Bb*	*Pp ww BB*	*Pp ww Bb*	*pp Ww BB*	*pp Ww Bb*	*pp ww BB*	*pp ww Bb*
pwb	*Pp Ww Bb*	*Pp Ww bb*	*Pp ww Bb*	*Pp ww bb*	*pp Ww Bb*	*pp Ww bb*	*pp ww Bb*	*pp ww bb*

FIG. 39.—Checkerboard of F_2 cross between a polled, black-faced, black-bodied Angus and a horned white-faced, red-bodied Hereford.

representing dominant characters with capitals, and recessives with small letters), a hybrid *Pp Ww Bb* is secured.

Angus	Hereford
PP ww BB	*pp WW bb*
PwB	*pWb*

Pp Ww Bb F_1 polled, white-faced, black-bodied hybrid.

Now if these F_1 hybrids are crossed to derive the F_2, there will again be eight different kinds of spermatozoa and ova, that is, the six factors will combine in all possible combinations as indicated in Fig. 39:

In Fig. 39 at least one large *P* determines polledness, at least one large *W* white face, and at least one large *B* black body; therefore, there appear:

27 polled, white-faced, black-bodied individuals.

9 polled, white-faced, red-bodied individuals.

9 polled, plain-faced, black-bodied individuals.

9 horned, white-faced, black-bodied individuals.

3 polled, plain-faced, red-bodied individuals.

3 horned, white-faced, red-bodied individuals.

3 horned, plain-faced, black-bodied individuals.

1 horned, plain-faced, red-bodied individual.

The Mendelian ratio is still intact, as there are:

48 polled to 16 horned, or 3:1.

48 white-faced to 16 plain-faced, or 3:1.

48 black-bodied to 16 red-bodied, or 3:1.

It will be seen that there are eight genotypes in the first phenotype listed above, the polled, white-faced, black-bodied; four different genotypes in the next phenotype, the polled, white-faced, red-bodied; four different genotypes in the next phenotype, the polled, plain-faced, black-bodied; four in the next, the horned, white-faced, black-bodied; two in the next, the polled, plain-faced, red-bodied; two in the next, the horned, white-faced, red bodied; two in the next, the horned, plain-faced, black-bodied; and one in the last, the horned, plain-faced red-bodied.

Multifactor Hybrids.—Mendel calculated the ratios for more than a trihybrid but never performed the experimental test. In the case of a monohybrid four individuals are to be dealt with

FIG. 40.—Diagram showing inheritance of polled, white face and black body characteristics and their allelomorphs in an Angus-Hereford cross through F_2.

in F_2; a dihybrid gives sixteen; a trihybrid sixty-four; one involving four pairs of contrasted characters would furnish 256 individuals in F_2; and if ten characters were considered simultaneously 1,048,576 individuals would have to be considered in the F_2 generation. It can readily be seen that the problem is becoming unwieldly. For this reason very few crosses involving as many as four pairs of contrasted characters have been worked out.

Little and Phillips report an experiment involving four pairs of independently Mendelizing factors in mice. They crossed a wild male of the genetic constitution *AA BB DD PP* (*A* for agouti pattern, *B* for black coat, *D* an intensity factor, and *P* a factor for eye coloration) on a pink-eyed, dilute, brown female of the genetic constitution *aa bb dd pp*. The observed ratios from such a cross in F_2 were in all cases very close to expectations. The chromosomal interpretation of the segregation and

recombination of factors in this cross is the same as was found in the mono-, di-, and trihybrids.

From the foregoing it is apparent that in practical breeding the only hope lies in dealing with not more than one or two characters at a time. Since unit characters usually behave independently of each other, one may breed for a single character until it is segregated out in a homozygous, that is, pure, condition, and then in the same way obtain a second character, a third, and so on.

Thus in a few generations of properly directed crosses there can be obtained combinations of characters united in one strain that formerly were never obtained at all or were only hit upon by the merest chance at long intervals. Herein lies the scientific control of heredity which the trinity of Mendelian principles, namely, independent unit characters, segregation, and dominance, has placed in human hands.[1]

It should be pointed out that in order to secure independent segregation in all the types of hybrids studied above it is necessary that the factors be located in different chromosomes. This of necessity limits in any species the number of pairs of contrasted characters that can show independent assortment to the number of pairs of chromosomes found in that species. Drosophila, for example, with four pairs of chromosomes could not manifest more than four pairs of independently segregating characters at any one time. No cases have been discovered where there are more independent pairs of contrasted characters than there are pairs of chromosomes. If in Drosophila five pairs of contrasted characters were considered at one time it would, of necessity, mean that at least two of these pairs of characters were determined by factors carried in the same chromosome. Such a condition is known as *linkage*.

THE MORE RECENT MENDELIAN PRINCIPLES

1. Linkage.—Students sometimes get the erroneous idea that each characteristic exhibited by an organism is the result of the action of one and only one factor in the germplasm. Such an idea is probably very far removed from the truth. If this idea were the correct one and these factors each an independent entity, so that they could be sorted and recombined at will, genetics would be a very simple proposition.

As a matter of fact, the development of any characteristic in an adult is probably the result of the action of a great many factors,

[1] WALTER, H. E., Genetics, p. 144, The Macmillan Company, 1919.

the specific action of one factor perhaps being essential. The determiners for the characteristics are not independent entities that can be juggled about at will; but they are organized in definite fashion into larger groups known as chromosomes. In other words, in each chromosome are located the determiners for a great many characters. Being so organized, it is but natural to suppose that the group tends to remain so organized in the chromosome and that there will be a tendency for factors located in the same chromosome not to assort independently but to remain more or less permanently linked together. This is actually the case.

Morgan cites the case of mating a fly (Drosophila) with two recessive mutant characters, black body color and vestigal wings (*bv*), to a fly with wild-type body color and long wings (*BV*). Such matings produce offspring all of which are of the wild type (*BV bv*). If one of these F_1 sons is back-crossed to a black, vestigial female two kinds of offspring are produced, half of them being black, vestigial (*bv*) (*bv*) and half wild type (*BV*) (*bv*).

> In other words, the two mutant characters that went in together, black and vestigial, have come out together; and their two normal allelomorphic characters, wild-type body color and long wings, have also come out together. There are no F_2 flies that are black and long, and none that are vestigial and gray, as would be the case if independent assortment took place.
>
> Unless we knew that the two characters black and vestigial are distinct mutant characters, the preceding experiment would not necessarily show that the characters are linked, because the same result would have followed if black and vestigial were both due to the effect of a single gene. Other experiments, however, show that they are independent characters.[1]

This case is that of a dihybrid like the previously mentioned cross of a smooth, black on a rough, white guinea pig, with the very essential difference that in this case an independent assortment is not secured as in the former, because the determiners for both the mutant characters, black body and vestigial wings, are carried in the same chromosome and therefore tend to stay linked together.

2. Crossing Over.—The foregoing instance of linkage was of the sort wherein whole chromosomes remained intact during matura-

[1] MORGAN, F. H., The physical basis of heredity, pp. 81–82, J. B. Lippincott Company, 1919.

tion or reduction. The male Drosophila and female silk-worm moth exhibit this phenomenon. There are, however, other instances wherein there is an equal interchange of chromatin material between two homologous chromosomes as they break apart after synapsis "as in the females of Drosophila, the males of moths and fowls, and in both egg cells and sperm cells of the plant Primula."

The physical behavior of the chromosomes is illustrated in Fig. 41.

FIG. 41.—Diagram illustrating chromatin interchange in single and double crossing over.

Morgan gives, among others, the following instance of crossing over in Drosophila:

When a black fly with vestigial wings is crossed to a wild-type ("gray") fly with long wings the offspring are, as we have already seen, "gray," long. If one of the F_1 females is back-crossed to a black vestigial male there are four kinds of offspring produced, *viz.*, the two original combinations, black vestigial, and gray long; and in addition two recombinations of these, *viz.*, black long, and gray vestigial. The two latter classes are called the crossover classes, or, more briefly, crossovers. The percentage of crossovers is definite for a given stock, of a given age, and under given environmental conditions. In this case the percentages are as follows:

NON-CROSSOVERS		CROSSOVERS	
Black vestigial	Gray long	Black long	Gray vestigial
41.5 per cent	41.5 per cent	8.5 per cent	8.5 per cent
83 per cent		17 per cent	

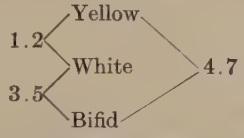
If a pair of chromosomes in the F_1 fly is represented as carrying the genes of the characters here involved, one member of such a pair carries both a gene for black and a gene for vestigial; the homologous member of the pair of chromosomes carries both of the normal allelomorphs, *viz.*, a gene for gray and a gene for long wings. When crossing over takes place so that a gene for black goes over into the other chromosome, the converse phenomenon takes place, a gene for gray goes over into the chromosome that gave up its black gene. It is the constancy of this interchange that makes the phenomenon reducible to exact mechanical treatment.[1]

[1] MORGAN, F. H., The physical basis of heredity, pp. 87–88, J. B. Lippincott Company, 1919.

3. Linear Order of the Genes.—The data of linkage and crossing over furnish the materials from which Morgan and his associates at Columbia have elaborated the theory that the genes lie in definite order in a linear series in the chromosomes. The proof of the theory lies in the fact that when three points are considered—*a*, *b* and *c*, for instance—the amount of crossing over between *ac* can be computed if the linkage relations of *ab* and *bc* are known, it actually being a function of the sum of *ab* and *bc* or of the difference between *ab* and *bc*, provided the points chosen are not so far apart that double crossing over may occur.

Morgan cites the following instance in Drosophila:

> When three mutant characters, yellow, white, and bifid, were all used together in a single experiment, it was found that there were 1,160 non-crossovers, 15 flies representing single crossovers between yellow and white, and 43 flies representing single crossovers between white and bifid. There were no flies representing crossing over in both regions at the same time, *i.e.*, there were no double crossovers. Thus the crossover value yellow white is 1.2, and the crossover value white bifid is 3.5. The same data give the yellow bifid crossover value of 4.7, which is precisely the sum of the two component values:



> The simplest way in which such a relation can be thought of is that the three genes stand in a line. Suppose a fourth linked gene *d* is added to the series. It is then found that *bd* is a function of the sum or of the difference of *b* to *c* and *c* to *d*. Four points arranged in a straight line still fulfil the relations here found. I know of no other geometric configuration that covers all these results—perhaps there is none. When we add more and more linked genes to the series, and find the same predictable relations continue to hold, the theory of the linear arrangement becomes firmly established. Perhaps the best proof of the linear order is found in the opportunity it gives for prediction; for when the relation of *d* to *b* and to *c* is known its relation to *a* can be foretold accurately.[1]

If during synapsis the chromosome is as apt to break at one point as at another, then, obviously, the farther apart any two factors lie in the chromosome the greater will be the liklihood of crossing over taking place, and conversely, the closer together

[1] Morgan, F. H., The physical basis of inheritance, pp. 119–120 J. B. Lippincott Company, 1919.

any two factors lie the less likelihood will there be of any crossing over taking place.

By means of the crossover values used to indicate the distance between loci of genes a very ingenious chromosome map of the four chromosome pairs in Drosophila has been prepared, on which scores of characters have been definitely located in the chromosomes (See Fig. 42). In the author's opinion such a feat rivals any other of man's scientific accomplishments.

4. Interference.—It has been proved by experiments, particularly with Drosophila, that crossing over is a matter of fairly large sections of chromosomes and not of individual points. After fusing during synapsis the chromosomes break apart again, and if crossing over has occurred it means that there has been an equal interchange of chromatin material between the pair of chromosomes involved—in other words, a section of one chromosome has gone over into the corresponding locus in its homologous chromosome and *vice versa*. This sectional mode of interchange brings it about that if a break occurs at any given point in a chromosome the contiguous portion of the chromosome is protected from coincident crossing over. This is known technically as *interference*.

5. Limitation of the Linkage Groups.—The final principle, namely, limitation of the linkage groups, means that the linkage groups in any given species cannot outnumber the pairs of chromosomes for that particular species.

The foregoing discussion of Mendelism has been largely in terms of lower plants and animals, but this should not lead to the assumption that these principles do not hold in all higher forms. The evidence available validates the conclusion that all of these principles are at work throughout all classes of farm animals. The task of tne future is to analyze farm animals in terms of the foregoing principles, and it may be that, in the process additional principles will be discovered.

Mendelism in Relation to Farm Animals.—The general application of Mendelian principles to all the higher animals seems to be established beyond a reasonable doubt. In such highly organized and specialized individuals it would seem probable that the working out of these principles may also have become exceedingly complex. This, no doubt, is the case, and the task of analyzing the higher animals for their unit characters and for the interrelations and interdependencies between them is an exceed-

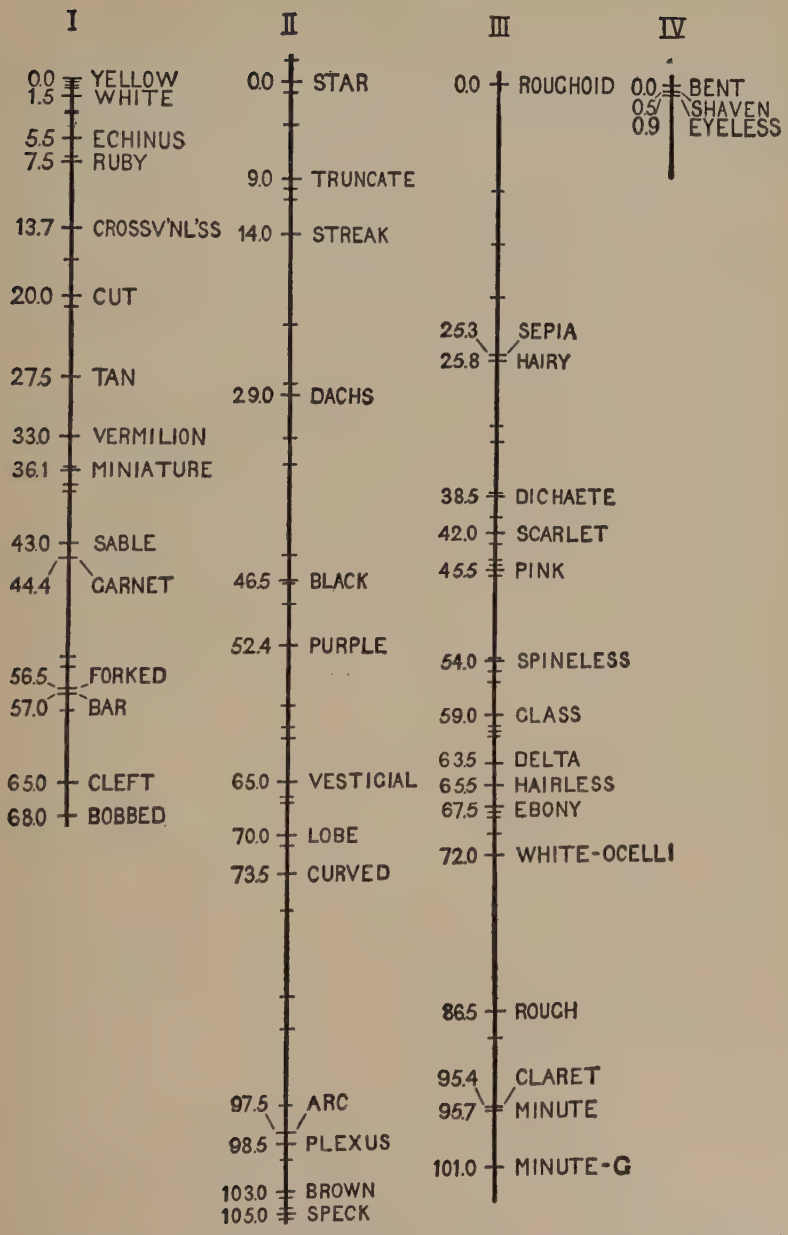


FIG. 42.—Diagram showing the location, in the four paired chromosomes of *Drosophila*, of the genes for various mendelizing characters. The X-chromosome with its sex-linked characters is at the left. The numerals indicate the supposed relative distances of the genes from the upper (zero) end of each chromosome as determined by linkage strengths in crosses. (*From Castle after Morgan, Sturtevant, Muller and Bridges, Genetics and Eugenics, Harvard Univ. Press.*)

ingly difficult and expensive one. Knowledge of unit characters and their behavior in transmission in farm animals is meager at present, but a start has been made and the prospect seems hopeful. A further discussion of this subject will be found in the Appendix.

Factorial Manifestations.—Factors or genes are the genetic representatives of specific characteristics. The exact nature or physico-chemical make-up of the factors is unknown. At present they are known simply by their actions. It is the purpose here to point out some of the ways in which the factors manifest themselves.

The simplest factor manifestation is of the sort where apparently one factor conditions the development of a certain characteristic, as, for example, the factor *P*, which brings about polledness in cattle. As a contrast to this may be considered the function of milk production, which is no doubt dependent on a great many factors, since milk production is a complex physiological phenomenon dependent among other things on the capacity, temperament, and vitality of the cow. One factor may have a very pronounced effect on the individual, as witness in peas, the factor *T*, which brings about tallness, whereas factor *t* brings about dwarfness; or the factor may cause the early death of the individual (lethal factors). On the other hand, the factor may condition the development of a minor characteristic, such as eye color. The white eye in Drosophila, however, is only one of several characters that such mutants exhibit, some of the others being a lowered fertility and vitality; thus one factor apparently affects many characteristics. The individuals of certain races may exhibit a great deal of variability, but the evidence would seem to point not to the unstable nature of the gene but rather to environmental effects as the source of this variability.

Entirely different factors may also bring about the identical characteristic in the organism.

> We find, in experience, that we cannot safely infer from the appearance of the character what gene is producing it. There are at least three white races of fowls, produced by different genes. We can synthesize white-eyed flies that are somatically indistinguishable from the ordinary white-eyed race, yet they are the combined product of several known color-producing genes. The purple eye color of Drosophila is practically indistinguishable from the eye colors maroon and garnet.[1]

[1] MORGAN, F. H., Physical basis of heredity, pp. 239–240, J. B. Lippincott Company, 1919.

In some cases one variety may carry one factor which, when supplemented by another factor from a different variety, may bring about a new characteristic, *e.g.*, one variety of white corn *CC pp* crossed on another white variety *cc PP* produces a purple aleurone color. In mating the hybrids the presence of at least one factor *C* and one factor *P* produces the purple color.

The mating of short-eared (100 millimeters) and long-eared (220 millimeters) rabbits usually produces offspring of an intermediate ear length. This has been explained on the basis of complementary factors, three being concerned. The long-eared rabbit is *AA BB CC* while the short-eared is *aa bb cc*. The presence of each dominant ear-length factor (capital letter) conditions an increased ear length of 20 millimeters over the short condition.

CHAPTER XI

VARIATION

For many centuries, species and varieties were believed to be immutable. The rise of many varieties of dogs from one or two remote ancestors by means of the principles of *variation* and *selection* and the same phenomenon in horses, cattle, sheep, and swine was pointed out in the introductory chapter.

Henry Van Dyke is reported to have said that there is one thing in which all men are exactly alike, and that is that they are all different. This statement also holds true for farm animals. To the observing it is quite evident that "the most invariable thing in nature is variation."

When it is considered that probably no two blades of grass, no two calves, or no two human beings have ever been just exactly alike (though identical twins are essentially so), a fleeting glimpse of the vast resources of nature is obtained. It would seem that the new plans and specifications must sometime be depleted, yet life flows along in its thousands of varieties and millions of individuals and each one is just that, an individual, different from all the rest of its kind. Fortunate, too, that this is so, because without this principle progress would be impossible. As has been said, "Variation is at once the hope and the despair of the breeder" the hope because through it may be produced offspring better than their parents, the despair because after animals have been raised upon a high plane they may and very often do vary again toward mediocrity. In general, it is true that "like produces like" but only in general; specifically it does not.

Cause of Variation.—There can conceivably be but two causes of variation. Either it is due to an internal vitalism or else due to the response of organisms to stimuli. General opinion leans towards the latter explanation. There are two types of stimuli that might conceivably bring about variation, one internal, the other external, to the organism. Any fully developed organism

is the result of the combined action of these internal and external stimuli.

$$\text{Variations} \left\{ \begin{matrix} \text{Autogenetic} \\ \text{Exogenetic} \end{matrix} \right.$$

The organism starts as a single-celled zygote, with its full complement of factors derived from both paternal and maternal sources. This genetic heritage has a tendency to react in a certain definite way, due to its chemical and physical make-up. The norm for this new individual may vary from that of one or both

FIG. 43.—Beth of Amherst 3rd. a Grand Champion at Eastern States Exposition (picture taken when dry). Her twin sister was nearly as poor a dairy type as she is good.

of its parents because of its different chromosomal content. During intra-uterine development any organism is subject to various influences from its mother, with whom it lives in very close association. Chemical products in the blood of the mother may be transfused into the circulation of the embryo and may react in various ways on the developing embryo or cause it to react in a variety of ways. The mother's blood or the fluid surrounding each cell may contain nutritive material which will assist in the proper growth and full development of the embryo. On the other hand, they may contain waste or toxic products,

secretions or hormones from various glands, and so on, any of which may cause the embryo to vary more or less from its original normal tendencies. Effects due to the parent's habits or to contingencies in the developing embryo itself cause many variations to appear in the fully developed organism, all the way from a doubling of parts, through various types of blemishes and malformations to an entire pinching off or absence of the part.

Environment and Somatic Variation.—Among the external stimuli are light, temperature, food, moisture, and other influences tending to make the organism deviate from its normal as specified by the make-up of the germplasm which gave rise to it. As pointed out by Babcock and Clausen, external stimuli may effect the development of characters in three ways: (1) They may modify the development of inherited characters, *e.g.*, red, white, or blue light causes marked variations in the Showy Sedum, even though the several plants be of the same genetic make-up; temperature affects the degree of pigmentation in moths and butterflies; food supply affects the relative size of body parts of Hyalodophina, a crustacean; moisture affects the plumage color of pigeons. (2) They actually condition the production of characters whose hereditary determiners are present in the germplasm. For example, light conditions normal development in plants; temperature, when low, causes red flowers in the Chinese primrose, when high, induces white flowers; the kind of food supplied to the larvæ of bees determines whether the females shall be fertile (queen bees) or infertile (workers); moisture concentration brings about development of abnormalities in black banding on the abdomen of Drosophila, a fruitfly. (3) They may cause germinal variations which result in the appearance of new heritable characters.

Environment and Germinal Variation.—It seems almost certain that early in the evolutionary process the environment must have wielded a marked influence on the simple forms of life and caused their germplasms to vary in different ways. Experimentally this is possible in plants and lower animal forms today. In higher animal forms, however, with their various adaptations for protecting the delicate germ cells, the possibility or extent of such external influences is much lessened. Parallel induction (same influence affecting both soma- and germplasm) in the cases of alcohol or lead poisoning must be admitted, but here the effect appears to be temporary.

Much work remains to be done in this particular field. Tower has pointed out:

> It is evident that the problem of germinal change is one of difficulty, and involves more of indirect than of direct methods of investigation. There is little reason to expect that present biochemical methods can give a solution, but they may give valuable suggestions for further indirect investigation. It seems not improbable, however, that this problem, like so many others in biology, must await the solution of the larger question of what life is before it will be possible to express in exact terms the nature of germinal changes. Our present status, with several methods of production and much knowledge of the behavior of induced germinal changes available, is a basis from which great advances in knowledge and in operation may reasonably be expected.

Heritability of Variations.—Variations may also be classified according to heritability. Conceivably, there can be but two alternatives—either a variation is heritable or it is not. Variations may be divided into three classes, namely, recombinations, mutations, and modifications, and may be classified under heritability as follows:

Variations	Heritable	Recombinations
		Mutations
	Non-heritable	Modifications or fluctuations

Recombinations.—For clarity, it should be recalled that the parents produce germ cells, spermatozoa and ova, containing chromosomes in which are located the determiners for all the characteristics that the individual may exhibit. These germ cells have all been through the process of reducing the number of chromosomes to one-half, so that, when the two (spermatozoön and ovum) unite, the normal number of chromosomes for the species will again be restored. It is a good deal as though two 25-cent pieces, two dimes, two nickels, and two pennies were laid out on a desk side by side. These may represent the pairs of chromosomes, one member of each pair having been put in by each parent. When this individual produces spermatozoa or ova, as the case may be, one member of each pair of coins will go to one of the two secondary germ cells produced, and the other member of the pair will go to the other. They form all the combinations that it is possible to form from the original coins. It, of course, is necessary to have in each new combination at least one 25-, one 10-, one 5-, and one 1-cent piece. The other member

of the pair in each case goes to the other cell, so that at fertilization, when spermatozoön and ovum come together and unite, each contributes a 25-, a 10-, a 5-, and a 1-cent piece, and the normal number for the species is once more restored.

Influence of Recombinations on Variation.—It will be recognized that with only four pairs of coins, or four pairs of chromosomes, it is possible to get a great many new combinations, 2^4 or sixteen, in fact. In the higher animals with twenty to fifty pairs of chromosomes the possibilities of the new kinds of

Fig. 44.—Two Ayrshire cows and their twin calves showing marked variation in amount of red color in the coat.

recombinations run into the millions. Now in addition to this it must be borne in mind that each chromosome probably carries determiners for several or a hundred different characters and that these characters may change from one chromosome to the exact position on the other member of the pair and *vice versa*—in other words, crossing over may occur. These principles of *independent assortment* and *crossing over* make the possibilities of the recombinations truly infinite. The workings of these principles are, no doubt, the greatest cause of variation in farm animals. They explain why a cow (scrub in this case) can be bred to a certain

bull and a heifer produced that yields 3,600 pounds of milk and later the same cow be bred to the same bull and a heifer produced that yields 6,100 pounds of milk. The first heifer yielded 31 per cent less milk than her dam, the second one yielded 17 per cent more than her dam. Or to cite a case from the purebreds, namely, of a purebred cow bred twice to the same purebred bull: In the first case a heifer resulted that yielded 6,200 pounds of milk, 14 per cent less than her dam, and in the second case a heifer that produced 9,800 pounds of milk, or 35 per cent more than the dam. Why? Because, as explained above, the chromosomes, which carry the determiners for all characters, *e.g.*, milk yield, tendency to fatten, polledness or hornedness, etc., go through the process of reduction, the factors separating or segregating out, thus being enabled to reunite into new combinations of various sorts. This chromosome mechanism is the most potent cause of variation.

Now it may be asked, why is a purebred animal better than a scrub? The purebred has been bred for a particular purpose for many generations, therefore, it seems logical to expect it to excel in the particular character desired, which it usually does. From a genetic standpoint, if capital letters represent the dominant, desirable characters and small letters the undesirable recessives, the chromosomes of the purebred have this make-up—*AA BB CC DD*, etc.—and the chromosomes of the scrub this make-up—*aa bb cc dd*, etc. During reduction one member of each pair of chromosomes goes to each secondary germ cell, therefore, the germ cell of the purebred will be *ABCD* and so on for hundreds of characters and those of the scrub will be *abcd* and so on. When they mate, the two germ cells come together, each one puts in one member of each pair, and the offspring genetically is *Aa Bb Cc Dd* and so on, and looks like the purebred because supposedly the large letters are dominant, in other words, hide the contrasted recessive characters. Regardless of looks, however, this hybrid should not be used for breeding purposes because when reduction goes on in its germ cells spermatozoa or ova are produced, in which these characters will unite into all possible combinations. It, therefore, would be possible to get all types of combinations of *Aa Bb Cc Dd* or, in other words, the ova and spermatozoa might be *ABCD, ABCd, ABcD, aBcD, Abcd* and so on through all the sixteen possible ways that these four pairs of letters could be combined. In plain words, the animal would not

produce a uniform kind of spermatozoa or ova genetically, therefore, could not breed true. The purebred breeds true because it is made up of *AA BB CC DD* and commonly produces but one kind of germ cell. What has been said here of the four letters is not to be taken literally, though the fundamental principle is entirely sound.

Perhaps it will be wondered why the two kinds of heifers, one a good producer and the other a poor producer, were secured from the identical mating of the two purebreds. It can be explained (provided both heifers had equal developmental opportunities) by saying that, though purebreds, both the parents were not, *AA BB CC DD*, etc., in their genetic make-up. Had they been, both daughters would have been the same in milk production. The two animals produced different sorts of offspring in the two cases because different kinds of spermatozoa and ova united. It is for the purpose of purifying these factors, getting them all to be *AA BB* etc., that inbreeding is sometimes practiced. Inbreeding does just this, tends to make the individual pure for all its characters. If the characters are desirable, improvement results; if they are bad or recessive, like *a* or *b*, then inbreeding tends to make them worse, *i.e.*, *aa bb* and so on.

Mutations.—Besides the different recombinations that might be inherited, there are mutations which are also inherited. These are probably due to chemical alterations in the determiners for certain characteristics in the germ cells of male or female or perhaps to a change in the number of chromosomes themselves. The chemical rearrangement of the atoms in the genes which may bring about mutations might be compared to the interchanging of a certain number of hydroxyl and hydrogen ions from one place to another in the structural formula for dextrose which converts dextrose into levulose. Or different atoms may be substituted for some already present, just as one may by substitution change methane (CH_4) to monochlormethane (CH_3Cl). Both the new arrangement of atoms and the substitution of one or more different atoms for others already present would supposedly give rise to variations. In the evening primrose, in which the normal number of chromosomes is 14, the following numbers of chromosomes, according to Gates, have been reported: 15, 20, 21, 22 23, 27, 28, 29, 30. These plants with a number of chromosomes other than 14 are mutations and have certain distinguishing soma or body characteristics.

The difference between a mutation and a freak should be clearly realized. A mutation is a sudden germinal variation *that breeds true.* A freak is probably a sudden somatic variation, such as a two-headed calf, a six-legged pig, and many others that may be seen at the circus, but which will not breed true. The freak has no value, and, while the mutation may not have value, it often does, and because of the fact that it breeds true the characteristic may be perpetuated. The best-known mutation among farm animals is, no doubt, the characteristic of polledness or hornlessness. These individuals arise from the mating of two

FIG. 45.—A sheep with very short and crooked legs after the style of the Ancon.

horned individuals, probably because of a chemical change of some sort in the chromosomes. No doubt, they have arisen in all the breeds at times and in most breeds they have been noticed and valued and a polled strain developed from them. The reason for the change in the chromosomes which prevents the horns from developing is unknown.

Another mutation, now extinct, occurred many years ago in sheep. Seth Wright, a Massachusetts farmer, had dropped in his flock a ram lamb that was a mutant, being low-backed, long-bodied, and having short, crooked legs, something after the fashion of a Dachshund. Farmer Wright recognized its value—

its type of build, while not interfering seriously with wool production, being a decided deterrent to the sheepish pastime of fence jumping. The ram, a mutant, was used for breeding, and from this start the Ancon breed of sheep, with the characteristics listed above, was produced, though the breed has long since been supplanted by the Merino.

The Mauchamp sheep of France, with a superior sort of fleece, are sometimes considered as a mutant race, but inasmuch as the original ram was a hybrid between a Mauchamp ewe and a Dishley ram this case, as Nathusius points out, must be removed from the records of actual mutations in domestic animals. Another character in sheep reported from Norway, namely, short ears, though of no practical importance, is, perhaps, a mutant.

Babcock and Clausen state as regards mutations in domestic animals that

> Any system of herd improvement founded on the search for and utilization of mutants is doomed from the beginning to failure, for mutants of a beneficial character appear so rarely as to have almost no practical significance. If by some fortunate chance a breeder should find himself in possession of a favorable mutant individual, however, it is a simple problem in Mendelism to establish its characters in a constant race.

For instance, if a mutant sheep were produced with no tail, a tailless breed could soon be developed and the trouble of docking saved.[1] No system of breeding has yet been advocated to produce mutations, perhaps none will ever be devised. Tendency to mutate, however, is very likely an inheritable characteristic, however, just as are all other features and traits exhibited by organisms.

Modifications.—These are impressed on the soma from the outside, while the two classes just discussed, namely, recombinations and mutations, are expressed from the inside, specifically from the germplasm. These last two are heritable, while modifications are non-heritable. This is once more the question of the inheritance of acquired characters, adequate supporting data for which belief are lacking. If it is possible to modify the function of any organism in a given way, it must be because the organism inherited the ability to react in such a way. This does not necessarily mean that offspring from such an individual would necessarily show the same aptitude to modification. That

[1] A mutant tailless strain is in process of formation in the West at present.

would depend on the breeding back of the individual in question. The possible effect of amphimixis, or the bringing together of two diverse bits of germplasm must also be taken into consideration. Animals of a good strain which are themselves stunted and not developed to the limit of their inherent capacities may beget offspring of a type capable of great development. Daughters of scrub cows, developed under an environment tending toward full development of capabilities, produced 13 per cent more milk and 12 per cent more butterfat than their scrub dams of the same type of breeding, which had been developed under less favorable conditions. It is the province of animal breeders to develop fully all the capabilities that their animals possess. Not that these so-called modifications will be inherited—they probably will not be—but if the parents exhibit favorable modifications it must be because they carry that particular type of germplasm, and unless previous breeding or amphimixis interferes, the offspring of such parents should exhibit like capabilities. Modification is an aid to selection, but like all other aids must subject itself to the breeding test.

Prepotency.—The term *prepotency* is often used in rather a loose fashion and is applied generally to males. It is usually associated with the general characteristic of vigor. That is, it is applied very often to an outstandingly vigorous male. The term really means the ability of an animal, male or female, to stamp its own characteristics on its offspring. For instance, the Hereford bulls used on the grade cattle of the range have put white faces on all the offspring of such matings. If a Hereford-Angus, cross is made however, a white-faced, black-bodied,[1] polled individual is produced and the question arises as to which animal is prepotent. Some will say the Hereford, because of the white face on the offspring. Others will say the Angus, because of the polled characteristic and black body. The truth is, however, that one is not justified in speaking of either animal as being prepotent. The animal is not prepotent; the various characteristics that the animal may exhibit may or may not be prepotent. In this case polledness of the Angus, white face of the Hereford, and black body color of the Angus are each prepotent. The same results would be secured no matter which one of the breeds in the above cross was selected as the male and which one as the female.

[1] The Angus might be heterozygous for color and therefore give rise to a red-bodied calf.

Graphically the results in regard to these three characters and with the dominant characters underscored might be represented as follows:

PP	polled		*pp*	horned	
ww	black face	Angus	*WW*	white face	Hereford
BB	black body		*bb*	red body	

PwB *pWb*

Pp *Ww* *Bb*

polled, white-faced, black-bodied hybrid

It is not enough, however, to say that certain characters are prepotent. When the above crossbred produces spermatozoa or ova, as the case may be, the factors will separate and recombine into all the possible combinations, reduction taking place at the same time, so that ova or spermatozoa of the following make-up are produced: *PWB, PWb, PwB, Pwb, pWB, pwB, pWb, pwb.* If this individual is mated to a Hereford, pure for horns, white face, and red body, or *pp WW bb*, and hence capable of producing only *pWb* spermatozoa or ova, calves will result 50 per cent of which will be polled and 50 per cent of which will be black-bodied. Thus, the characters which are fully prepotent in the purebred, namely, polledness and black body, cease to be fully prepotent in the crossbred, because the crossbred produces more than one kind of reproductive cell, actually producing eight different kinds as regards these three characteristics of polledness, face color, and body color. The above characters are simple in their nature, being controlled specifically by one factor, although many other factors may be involved. According to Wright:

> Most characteristics probably depend on a large number of hereditary units, but nevertheless the nature of prepotency is believed to be essentially the same. So far as there is prepotency, it is a property of characteristics (or really of the hereditary units back of the characteristics), not of individuals, breeds, or sexes, and whatever the characteristics, there can be no prepotency unless the individual produces only one kind of reproductive cell so far as it is concerned.

Technically, prepotency depends upon the character being dominant and the individual being homozygous, that is, the individual must carry *AA* in the chromosomes of his spermatozoa or her ova, not *Aa* or *aa*. The more prepotent an individual is the less the probability of variation, good or bad.

Telegony.—Telegony may be illustrated by the more or less common belief that after a female has born young by a certain

male her subsequent offspring will show characteristics derived from the previous sire. The classic example is that of a mare which bore offspring by a quagga and later produced horse colts which showed some striping. Numerous attempts have been made to confirm this by crossing mares and zebras, but in all cases they have failed. The flasic elements that determine the characters of any individual are the ovum and the spermatozoön uniting to produce it. Spermatozoa from this first service could not possibly live over a gestation period in the female organs to fertilize the next egg, as they live for a very few days at the most. If this first offspring had any influence on other undeveloped eggs in the ovaries it would come under the heading of the inheritance of acquired characters, which phenomenon is discussed fully in Chap. XII. Mumford and Hutchinson made investigations in the mule-breeding district of Missouri, where mares often bear mule and later horse colts, but could find nothing to substantiate telegony. In the light of present knowledge of inheritance, telegony has neither experimental nor theoretical basis.

Maternal Impressions.—Belief in maternal impressions assumes that what a pregnant mother may see, hear, or experience may influence her offspring. In general, this old belief can be repudiated also, because, as Marshall points out, if it worked, all calves born in the spring up north would tend to be white because the mothers have viewed a white landscape all winter, and similarly calves born in the fall would be green. There is no direct nerve connection between parent and offspring to afford means for transporting ideas. Animal experiments have all given negative results in this field. It is, indeed, a fortunate provision of nature that in the higher animals the embryo is so well protected from all external influences. If material impressions were actually registered on the offspring all types and races would have long since become a hideous, conglomerate mess.

Breeding System and Variations.—The system of breeding in vogue will have a very decided influence on variation. If variations are desired, then the system to use is crossbreeding. This crossing of species, or varieties within the species, gives rise to many and devious variations because it brings together diverse kinds of germplasm. On the other hand, the system diametrically opposed to the above, namely inbreeding, has just the opposite tendency. Inbreeding tends to simplify the germplasm of the individual so produced, tends to make it have the same kind of

determiners in the germplasm, and hence reduces the chance for variations. These breeding systems will be discussed more fully elsewhere.

Nicking.—If offspring from a certain mating are of a high order of excellence then, breeders say, the parents "nicked" well. It sometimes happens that the mating of two rather mediocre individuals produces an offspring of a very high degree of merit in certain features of form or function, because the parents "nicked" well or, rather, this favorable individual arose because each parent supplied factors to the offspring, the combined manifestation of which produced a high-class individual. This probably is a case of complementary factors, the existence of which can only be known through breeding trials. When such animals arise their breeding ability must receive careful scrutiny before they are approved, it being possible that their diverse origin will manifest itself in their offspring, though this is not necessarily to be expected.

Variation Guided by Selection.—While it may be questioned whether selecting animals with a definite end in view can specifically be said to cause variations in that direction, it is, nevertheless, true that one variation in a given direction seems to make other variations in that direction more probable. Thus it is well known that by selecting Holstein's or Ayrshires the proportion of pigmented to non-pigmented area may be shifted from one of almost entire pigmentation to one almost white. Likewise, in Herefords the white of the face, which behaves as a unit in inheritance, may be increased or decreased in area. Functional variations, such as speed in horses, milk production in cattle, wool production in sheep, and so on, can also be guided by selection—in fact, it has been selection, both natural and artificial, which has given rise to most varieties and perhaps species. Castle states as an interpretation of factorial behavior in such selection:

> Many students of genetics at present regard unit-characters as unchangeable. They consider them as impossible of modification as are the atoms. To recall Bateson's comparison, the carbon and oxygen of carbon monoxide (CO) are each unchangeable. Adding another atom of oxygen does not alter them, though it changes radically the compound formed, which becomes carbon dioxide (CO_2), possessed of very different properties. But the carbon and the oxygen are still there, unaltered and recoverable. This question is one of great practi-

cal importance—are unit-characters as constant as atoms, so that we can merely recombine them, or are they different in nature from atoms, so that we can modify as well as recombine them? Much careful work has been devoted to the solution of this question. It was at first assumed from chemical analogy that characters which behave as units in heredity must, like C and O in the case of carbon dioxide, emerge from combinations unmodified. But presently case after case came to light in which this was not true. Albinism emerged from crosses tainted with color; clear yellows emerged from crosses intensified to red, or diluted to cream, or sooty with minute quantities of black; patterns such as are seen in Dutch or in English rabbits, or in hooded rats, emerged considerably altered in appearance. Facts such as these were interpreted

FIG. 46.—Inheritance of a recessive pattern of white spotting seen in "hooded" rats. The parents (at the left) are a homozygous hooded mother and a heterozygous "Irish" father (black with white belly). An entire litter of their young is shown at the right. Four are homozygous hooded like the mother, five are heterozygotes like the father. Note fluctuation in both classes. Such fluctuations are found to be in part heritable. (*Photo. from Castle, Genetics and Eugenics, Harvard Univ. Press.*)

in two different ways. It was assumed by some that the actual unit-character, factor, or gene involved was subject to quantitative and possibly to qualitative change. By others it was assumed that the observed character changes were not due to changes in single genes but to the supplemental or modifying action of the other genes. For example, the hooded pattern of rats clearly behaves as a simple unit-character allelomorphic to Irish pattern or to self in crosses. But the hooded pattern as seen either in purebred or in crossbred litters of young varies slightly, and such variations have a genetic basis, since by selecting either the whitest or the blackest individuals one can either whiten or blacken the average racial conditions. The question now arose whether the observed changes had occurred as a result of change in the single unit-charater or gene clearly concerned in the case, or whether this was due to other agencies. To test the matter the selected races, now modified genetically in opposite directions, were crossed

repeatedly with a non-hooded (wild) race. The recessive hooded character disappeared in F_1 but was recovered again in F_2 in the expected 25 per cent of this generation. These extracted hooded individuals, following each cross, were less divergent than their hooded grandparents from the ordinary hooded pattern. After three successive crosses (six generations) the whitest individuals extracted from the dark hooded race were no darker than the darkest individuals extracted from the white hooded race. In other words, repeated crossing with the non-hooded (wild) race had caused the changes in the hooded character, which had been secured by selection, largely to disappear. This result shows conclusively that the changes in question had not occurred in the gene for the hooded pattern, but in the residual heredity. Other cases of apparent gradual change in unit-characters under the action of selection may be explained in a similar way. Accordingly we are led to conclude that unit-characters or genes are remarkably constant and that, when they seem to change as a result of hybridization or of selection unattended by hybridization, the changes are rather in the total complex of factors concerned in heredity than in single genes.

FIG. 47.—A series of grades for classifying the plus and minus variations of the white spotting pattern of hooded rats. (*Photo. from Castle, Genetics and Eugenics, Harvard Univ. Press.*)

Nevertheless changes do sometimes occur in single genes. Such, we assume, are the several unit-character variations described in previous chapters, which form the basis of the varieties of domestic animals and cultivated plants. These occur singly and sporadically as changes each in a particular locus or part of a system of genes. By hybridization these isolated changes are later combined in any desired fashion. Change in a genetic locus, that is, the appearance of a new gene, is in the terminology of Morgan called a mutation, but this use of the term differs fundamentally from that of de Vries. There is no known means by which a mutation, in this sense, can be brought about. Genes are discovered, not made, in laboratories, and may be manipulated by hybridization but not changed. The suddenness of their coming and their stability are implied in the term mutation.[1]

[1] CASTLE, W. C., Genetics and eugenics, pp. 227–230, Harvard University Press, 1924.

Type and Frequency of Variation.—All animals will produce variations to a greater or less degree depending upon the interaction of a great many factors. Sometimes extremely valuable animals arise from the mating of mediocre parents as described above. Such variates should be studied carefully as to their ability to transmit their own desirable features and nothing along this line be taken for granted. Of decidedly more value than the animal which produces one such outstanding individual and a host of inferior ones is the animal which has a tendency to beget a uniform lot of offspring better than the preceding generation, even if the increase in excellence is small in each individual. To students of animal husbandry the fact of variation is too self-evident to need any elaboration.

CHAPTER XII

ACQUIRED CHARACTERS

The inheritance of acquired characters has been called "one of the historic battle grounds of biology" and the issue seemingly is not yet settled. The animal breeder is vitally interested in the solution of the question, Are acquired characters inherited? The successful breeder seeks to develop for himself and to leave to posterity a better type of animal than the one with which he was supplied at the beginning. It is perfectly natural for him to hope and perhaps believe that any increase in quantity or quality of product he can bring about will be cumulative in the animals.

Acquired Characters Defined.—Before proceeding to a discussion of the evidence pro and con it is essential to define specifically what is meant by an acquired character. Shull defines acquired characters as "those modifications of bodily structure or habit which are impressed upon the organism during its individual life." As Thompson has stated it, the precise question at issue is this: "Can a structural change in the body, induced by some change in use or disuse or by a change in surrounding influence, affect the germ cells in such a specific or representative way that the offspring will through its inheritance exhibit, even in a slight degree, the modifications which the parent acquired?" Any one of the higher organisms is the result of the union of a certain spermatozoön with a certain ovum. The chromosomal content of the particular spermatozoön and of the ovum that have united to produce any given individual determines the normal characteristics for this individual. With normal nutriment and a normal environment the individual will approximate its own norm as specified through its inheritance. Now both the anatomy and physiology of the organism are perfectly capable of modification and the precise question at issue is whether or not such bodily modifications will be impressed upon the germ cells and thus become a part of inheritance.

In an evolutionary sense all the characteristics which present-day organisms exhibit have been acquired for evolution teaches that life originated in a very simple form and that it has gradually grown more complex—in other words, has ever continued to evidence new characteristics. Even this, however, is far from proof that the somatic cells caused changes in the germ cells. May not the reverse of the last statement be the truth of the matter? Aligning cause and effect into their true relationship is not always an easy thing to do.

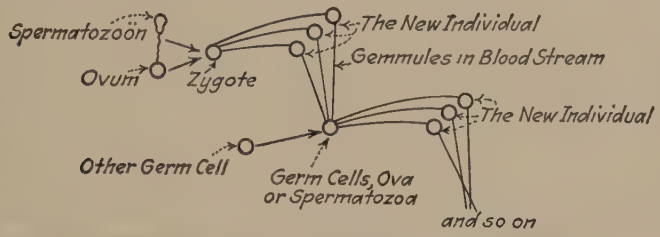


FIG. 48.—Schematic representation of the supposed method of transmission of acquired characters.

Lamarckism versus Weismannism.—Lamarck, a French scientist, and Darwin, the famous English author of "The Origin of Species," believed that acquired characters could be inherited, and for a mechanism it was postulated that the blood stream which bathes all parts of the body would have something (gemmules) put into it by the part affected or by the character acquired and

FIG. 49.—Schematic representation of the continuity of the germplasm. The drawing also illustrates the fact that germ cells arise from previous germ cells rather than from present somatoplasm.

that the blood, later flowing to testicles and ovaries, would deposit this something in the ova or spermatozoa and thus bring about the development of the character in the offspring. This is the theory of pangenesis.

Weismann has been the chief antagonist of the theory of the inheritance of acquired characters, and he also developed the idea of the continuity of the germplasm. Under this conception

the germ cells that any individual produces are thought of as arising, as do all the other cells of this individual, from the original zygote. Under this view the type of germ cell produced is dependent on the nature of the original zygote and is not affected by the soma or body which has also arisen from the original zygote. The accompanying diagrams should make clear the differing features of these two systems.

Requirements for Experimental Proof.—Babcock and Clausen say:

> To satisfy the rigid requirements of an experimental proof any evidence of the inheritance of acquired characters must fulfil the following conditions:
>
> First, a specific character or modification in the body or soma must be impressed upon the organism by a known factor in its environment or in its exercise of bodily function.
>
> Second, the character or modification must be new. There must be no question of the reappearance of ancestral traits or characters, or of the specific relation of the determining factor to the character or modification in question.
>
> Finally, the induced change in the organism must reappear to some, though not necessarily to its full degree in succeeding generations in the absence of the original factor which determined its production. Other conditions in the life of the offspring must remain unchanged.

The problem of the inheritance of acquired characters can be conveniently divided into the four following categories: (1) anatomical modifications, (2) environmental modifications, (3) functional modifications, and (4) pathological modifications.

Anatomical Modifications.—There is abundant data relating to mutilations. When the tail of a sheep is docked the sheep has acquired a character during its individual development, namely, taillessness. It is also recognized at once that this characteristic is not passed on to descendants of this sheep, but in succeeding generations it will be necessary to dock the lambs notwithstanding the fact that docking has been practiced for hundreds or thousands of generations. In this category come also the clipping of the horns of cattle, of docking horses' tails, of clipping dogs' ears and tails, etc. In none of these cases is the acquired character continued in the offspring. In the human family there might be mentioned circumcision, which has been practiced among the Jews for thousands of years, and also the binding of feet to prevent their full development by Chinese

women. Here, no more than in the cases cited of farm animals, is there found evidence that these acquired characters are being inherited in even the slightest degree. Weismann in order to test this hypothesis cut off the tails of mice for nineteen generations in succession and secured no shortening of the tails nor absence of tails in any of the descendants. As Walter remarks: "It is a good thing that children of warriors do not inherit their parents' honorable scars of battle else we would have long since been a race of cripples." The same author also remarks in this regard that "evidently wooden legs are not inherited but wooden heads are."

Environmental Modifications.—The second category is that of environmental effects. Examples from both the plant and animal kingdoms can be cited. Capsella, a wayside weed, has gradually climbed to a mountainous situation. As it climbed it "acquired" a dwarf character—at least it grows luxuriantly in the valley and is small, compact, and dwarfed in its mountain home, and when taken back to the valley continues in its dwarf characteristics. This can just as well, if not more logically, be explained by saying that those plants germinally constituted so that they grew somewhat dwarf would, for that reason, have a better chance of surviving under the more rigorous conditions and decreased food supply which prevail in an ever-increasing degree as the mountains are ascended. In other words, the force bringing about the change was not the inheritance of acquired characters, but "natural selection," which no doubt always has and always will, provided man does not interfere, weed out those types and individuals poorly fitted for their environment and preserve and prosper those better fitted to survive under the existing conditions. Another example is the wind-lashed trees of our sea coasts, with all the branches growing out on the land side and pointing landward, but it is not known that seed from such trees would produce trees with that peculiar habit of growth if the trees were grown where the almost steady sea breezes did not blow. The case of the persistent sunburn of white men long resident in India might also be mentioned, but this "acquired characteristic" fails to reappear in their children born in England.

Ponies inhabiting the Shetland Islands are dwarfed because of the harsh climatic conditions and resultant scanty food supply. If brought to America's corn belt, such animals would no doubt give rise to offspring which would greatly excell them in size.

Now if these larger offspring, after reaching maturity, are returned to the Shetland Islands will they continue to produce offspring which will attain large size? It is very unlikely that they will, and, even though they did, natural selection would give as logical and perhaps a more reasonable explanation than the inheritance of acquired characters could muster.

Functional Modifications.—The third category relates to inheritance of functional modifications due to use and disuse of parts. From a practical standpoint, along with the inheritance of disease, this probably furnishes the most interesting phase of the subject. It will be well at this point to examine critically just what is meant by acquired characters. Is the term more or less a misnomer? If so, would it not account for much of the loose thinking and arguing over this much-debated question? As Davenport suggests, the differences between animals in a given species are differences of degree and not of kind—they are *quantitative* and not *qualitative*. Horses show horse characteristics and not rabbit characteristics, except as both have certain general characteristics in common; cattle show characteristics of the cattle family and not those of the swine family, except as they have certain ones in common. Horses have draft power or speed, cattle give milk, hogs lay on fat—some, of course, to a greater degree than others—but they all exhibit the characteristics of their particular species and not the particular characteristics of other species. In other words, they inherit in the germplasm all the potentialities of their species in greater or less degree, depending upon the strain to which they belong. In addition, the environment in which they develop and live determines as to how far these potentialities are developed. Therefore, if a horse is able to trot fast because of his having inherited the tendency and because the tendency has been given play for full development by a fast track, careful trainer, proper harness, and so on, or if a cow inherited the tendency to produce large quantities of milk and this proclivity has been subsequently fully developed by proper care, feeding, and management, is the assumption at all justified that these animals have acquired any new characteristics? The fair answer is: No. The horse has not acquired new cow characteristics nor the cow new horse characteristics, nor have any new characters been acquired whatsoever. Inherent characters have been developed, perhaps exceedingly well developed, but no new ones have been acquired.

The point at issue is whether or not any increased functional activity will be registered in the germ cells and thus influence future offspring. Under this heading Redfield's theory of "dynamic" evolution can be discussed. This is the belief that the exercise of any organ or function results in a corresponding storage of energy in the germ cells, such that the effects are transmitted to the next generation—in other words, that these "acquired characters" are transmitted. This theory would postulate that if a cow were developed from an 8,000-pound two-year-old into a 16,000-pound ten-year-old the calf produced in her tenth year would be a much higher milk producer than the one produced when she was two years old, due to the cumulative effect of the increased production she had attained, the same bull having been used to sire both heifers. This has a distinct practical bearing in all classes of livestock. In his work to try to prove the existence of the inheritance of this acquired character or development in fast horses, Redfield first computed the average age of the immediate sires of the first 1,000 stallions taken alphabetically from the American Trotting Register, which he found to be 9.43 years. He then computed the average age of all the sires, four generations back, of the entire class of 2.10 trotters, a faster class than that dealt with previously, the upper limit for admission to the Register being 2.30, and this average he found to be thirteen years. From this material he concluded that the 2.10 class was faster than the group first considered because their sires had gradually grown more speedy as they increased in age up to thirteen and that they had transmitted this dynamic development to their offspring. Marshall critically points out the following shortcomings in Redfield's work. In the first place, he took in one case the immediate sires and, in the second case, all the sires included in the four generation pedigrees. Marshall reminds us also that these four generations carry us back over the formative period of the trotting horse to the time of Hambletonian 10, who was himself a great sire of speed and left many sons and grandsons, which, bred to faster mares, were even better sires of speed than he. Taking only the immediate sires of the 2.10 list, as was done with the first list of sires, Marshall finds the average age to be 9.41 years, nearly the same figure Redfield secured for the first group, 9.43, and evidencing no advantage of the old sire over the young one. In this matter of increased speed in succeeding generations of horses it has not been

proved that functional modifications have not been continued in the next generation, though it is a biased mind which would attribute all increase in speed to this factor and fail to recognize possibilities in amphimixis, possible mutations, better environmental influences, better harness and training methods, faster tracks, more skilled drivers, etc. Also, as has been suggested previously, is it not more likely that the germ cells caused the somatic changes rather than that the soma caused the germinal changes?

Advantages in Developing Functional Modfiications.—There is no conclusive scientific evidence in support of the inheritance of "acquired characters" as regards functional modifications or use and disuse of parts. This fact, however, should not influence breeders to decrease their efforts to provide the most favorable environment and to attain the fullest development of their breeding stock. Whether functional modifications are or are not inherited, breeders should still seek the germplasm carrying the greatest possibilities for high-class production and should seek, when offspring come from such germplasm, to place it in the best environment and supply the most studied feeding and management in order that its inherent capabilities may be developed to the fullest extent. Not that one must believe that this acquired development will be transmitted, because there is no sure ground for any such belief, but it is desirable to know the horse of greatest speed, the cow of highest production, the meat animals with the greatest tendency to fatten, and the sheep capable of the greatest production of high-quality wool and mutton, because, if in general, "like does produce like," it is such germplasm that should be used for increasing herds and flocks.

Pathological Modifications.—The fourth and last category, namely, the inheritance of disease, is also a consideration of vast practical importance. It should be borne in mind that, from a scientific standpoint, the only thing that is inherited is the germplasm, more particularly the various factors carried in the chromosomes. From this standpoint it will readily be seen that there is no more true inheritance in the case of disease than there was in the case of functional development. This problem, however, like the latter, has a very practical bearing, and while it may be said that although in neither case has the affirmative been proved, yet this lack of proof does not necessarily preclude the possibility of its existence. One of the commonly cited cases under this heading is that of tuberculosis. This, however, is

clearly a case of reinfection in the offspring, abundant opportunity for which is furnished in the intimate relations between parent and offspring, though it is very possible and no doubt true that the tendency or susceptibility to the disease is inherited in the weak germplasm from which have come both parent and offspring. It is well known that it is possible to produce healthy calves from tubercular cows and bulls, provided the calves are at once removed upon being born and taken to a clean barn—in other words, that the opportunity for the parents to reinfect the offspring is removed.

In this regard it may be well to mention the factor of immunity to certain diseases which exists in different species and varieties. If, for instance, a husky Irish policeman and an anemic Jew employed in a sweat shop were both exposed to the same kind and intensity of tuberculosis the husky policeman would be more apt to succumb to the disease, because, in the Jewish race, selection has established at least a partial immunity to this disease. The zebu is being crossed on the native cattle of Texas because of the former's relatively greater resistance to tick fever. The mule-foot hog is often claimed to be immune to cholera, though the claim has never been scientifically tested and substantiated. The microscopic organisms causing various diseases, if present in the blood of a parent, may be carried to and deposited within the ovum before it is fertilized. Such organisms, although not part of the chromosomal material which alone is heritable, are carried in the same cell with it and will thus cause the disease to reappear in the offspring; in other words, the reinfection may come either previous or subsequent to birth. The organisms causing pebrine in silk moths, Texas fever in cattle, and syphilis in man are of this type, but, as Walter says, the disease is no more inherited than a grain of sand placed within the ovum would be inherited, though, of course, for all practical purposes, it amounts to the same thing, as the offspring will suffer from the disease in question.

Influence of Genes on Pathological Modifications.—A very interesting study of disease susceptibility and resistance has lately been reported by Dr. L. C. Strong[1] of St. Stephens College. The following quotation is taken from his paper:

[1] Strong, L. C., Inheritance of cancer, *Jour. Heredity*, **15** (8): 355–360, 1924.

My first experiment dealt with the inoculation of a malignant tissue (adeno-carcinoma) subcutaneously into a series of hybrid mice of known relationship. Two original stocks of mice were employed. Every individual of the first stock (*dBr*) grew the transplant progressively; and every individual of the second stock (albino) proved to be resistant to the same tissue. By crossing these two distinct races of mice, a hybrid generation, known as the first filial generation, was produced, all the individuals of which reacted to the transplant as did the first original stock, that is, all the individuals grew the transplant progressively. By mating two individuals of this hybrid first filial generation together, a second filial generation was obtained that contained two classes of individuals as far as their physiological reactions to the same transplanted tissue was concerned. Three individuals out of every four obtained were like the original susceptible race and grew the tumor progressively; one out of every four individuals was negative like the second original albino non-susceptible race: a typical 3:1 ratio was obtained. This experiment demonstrates, therefore, that susceptibility to a transplantable tumor is dependent upon the same ultimate mechanism that the inheritance of eye pigmentation apparently is dependent on. A particular individual grows a transplanted tumor because there is present in its ultimate make-up at least a single germinal determiner for a special physiological function that was obtained from the zygote that gave rise to the individual.

Arguments against Inheritance of Acquired Characters.—The reasons for the general unwillingness at present to subscribe to the belief in the inheritance of acquired characters may be grouped as follows:

1. There is no known mechanism in the body capable of impressing soma or body changes on the germ cells.

2. The evidence, while considerable in some cases, is by no means conclusive.

3. The theories of the continuity of the germplasm and of germinal variation can account sufficiently well for all observed facts of heredity.

In order to study the effect of the soma on the germ cells, Dr. Castle at Harvard removed the ovaries of a white guinea pig and substituted the ovaries of a black guinea pig. The operation was entirely successful, and in due time the animal was bred to a white male and produced in all three litters totaling six individuals. This female was white (with substituted black ovaries) and was bred to a white male. White bred to white in guinea pigs invariably produces white offspring, but in this case all the offspring

were black. Some of these in later breeding trials behaved as normal black guinea pigs would be expected to behave. This critical experiment shows that the ova produced by those two black ovaries which had been transferred to a white body were, after a year's location in their new environment, still producing black ova, and it is, indeed, inconceivable that they could ever have produced any other kind. This experiment indicates that there is no mechanism in the body capable of impressing soma or body changes on the germ cells, though it, of course, does not prove this to be absolutely so, it being impossible to prove a universal negative.

Parallel Induction.—It is well known that the same thing may affect both body or soma and germ cells, as, for instance, alcoholic or lead poisoning, etc., but this matter of the same thing affecting both does not come within the definition of an acquired character, which was that the modification must be first impressed upon the soma by a known factor in the environment or in use and disuse of parts and the soma in turn impress the modification on the germ cells.

Summary of Inheritance of Acquired Characters.—Castle gives the following summary on the inheritance of acquired characters:

> Notwithstanding the fundamental nature of the problem of the inheritance of acquired characters, and all that has been said and done to solve it, it still remains an unsolved problem. So far as the inheritance of mutilations, disease, and induced epilepsy is concerned, the evidence is negative or inconclusive. Acclimatization, the effects of changed food supply, and temperature effects can be explained quite as well on other grounds as on that of the inheritance of acquired characters. Pressure and light effects are somewhat more easily explained as cumulative from generation to generation, *i.e.*, as inherited acquired characters, than as due merely to germinal variation. The same is true of instincts, which if interpreted as inherited habits, afford the strongest outstanding evidence for the inheritance of acquired characters. Nevertheless even here an alternative explanation is possible . . . If the germ cells are capable either directly or indirectly of modification by outside agencies, evolution guided by the environment must be, in some measure at least, a reality. The truth then lies neither in the extreme Lamarckian view that all acquired characters are inherited nor in the extreme Weismannian view, that no extraneous influences modify the germplasm, but somewhere in between.[1]

[1] CASTLE, W. E., Genetics and eugenics, pp. 44–46, Harvard University Press, 1920.

Practical Phase of Inheritance of Acquired Characters.—Breeders should continue to develop their animals to the utmost. If this development is cumulative from generation to generation breeders will profit thereby. If not, they will at least be able to see which animals are inherently capable of responding in the fullest degree to a favorable environment and then, through selection of these animals as breeding stock and through wise matings, they will be able to bring about a gradual improvement in the stock under their care.

CHAPTER XIII

SEX DETERMINATION

For obvious reasons, man has always been keenly interested in the factors determining sex, with the hope that he might ultimately find ways and means of controlling them to his own benefit. Because of the wide interest and enormous value of such knowledge there have been conceived in men's minds a great number of different hypotheses regarding sex determination and its control. Over 500 of these *theories* have been recorded. One theory states that the right testicle secretes male-producing spermatozoa and the left testicle female-producing spermatozoa. The same reasoning is often applied to the ovaries of the female. Many breeders believe that alternate heat periods are productive of opposite sexes. The same idea is sometimes applied to service at early and late portions of the heat period. Such theories as these have easily been proved false. One of the most weird superstitions states that "if a man has a sty on his eye, he concludes his aunt is pregnant. If the sty is on the upper eyelid the offspring will be a boy; on the lower a girl." Any theory for sex determination must, from the very nature of the case, be correct half the time, the offspring, of necessity, being either male or female, in most species these occurring in equal numbers. Any theory to be valid, however, must be true not in half but in all cases. There are, in the main, two opposing types of theories of sex determination which are held at the present time. One of these is the chromosomal theory, which is a morphological one. The other is the metabolic, a physiological theory. The data supporting each theory will now be presented.

Sex Ratios.—By the term *sex ratio* is meant the number of males in proportion to 100 females. The following table has been compiled from Jull. Babcock and Clausen, Ibsen, King, and some original data.

TABLE XIII.—SEX RATIOS IN ANIMALS

Animal	Sex ratio	Authority
Horse	102.44	Doncaster
Horse	98.30	Dusing
Cattle	104.86	Wilckers
Cattle	99.62	Rice
Sheep	98.34	Darwin
Swine	108.74	Wilkens
Fowl	97.28	Darwin
Fowl	97.64	Jull
Rat	104.60	King
Rat	104.60	Cuenot
Guinea pigs	103.34	Ibsen
Guinea pigs	92.00	Detlefsen
Average of all	100.98	

From the above data the conclusion may be drawn that, while there may be influences tending toward a preponderance of males or of females, in certain instances, by and large, nature tends to keep an even balance between the sexes.

XY Type of Sex Inheritance.—*Drosophila melanogaster*, the common fruitfly, has been more thoroughly studied, from the standpoint of inheritance, than any other species, and the study has yielded a rich reward. Along with the knowledge gained regarding behavior of factors in transmission from parent to offspring has come definite knowledge regarding sex and what determines it. There are two sources of such information, one cytological and the other the behavior of sex-linked factors. Cytology has established the fact that the normal number of pairs of chromosomes in Drosophila is four. Of these, three pairs are autosomes and one pair sex chromosomes, and while both sexes have antosomes which are morphologically identical, there is a characteristic difference between male and female as regards the sex chromosomes. The female has two so-called X chromosomes, while the male has one X chromosome, and one Y chromosome. The diagram on page 159 should make this clear.

After reduction has taken place as shown in the diagram there can be but one sort of ovum produced, *i.e.*, every ovum will contain one member of each pair of chromosomes, and each one will, therefore, contain one X chromosome. In the male, after reduction, there can be two kinds of spermatozoa, both of which are

similar as regards autosomes, but different as regards sex chromosomes, one having an X chromosome and the other a Y chromosome. Presumably, these kinds of spermatozoa are produced in equal numbers. Starting with an ovum containing an X chromosome and adding a spermatozoön also containing an X chromosome will give an individual with two X chromosomes, or a female. Starting with an ovum containing an X chromosome and adding a spermatozoön containing a Y chromosome will give an individual containing both an X and a Y chromosome, or a male. Cytological evidence, therefore, proves beyond a reasonable doubt that, in Drosophila, sex is determined at time of fertilization by the kind of spermatozoön that fertilizes the ovum, since the sexes invariably show the differences just outlined.

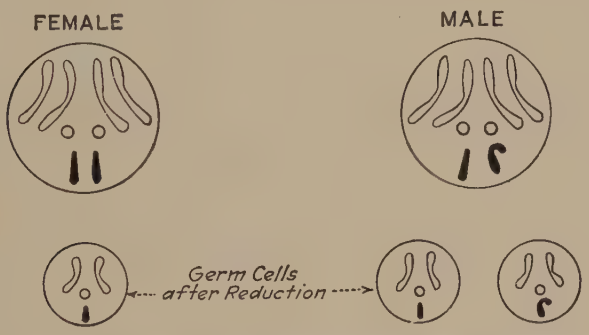


FIG. 50.—Diagram of nuclei of male and female germ cells in *Drosophila* showing the kind of ova and kinds of spermatozoa produced.

Sex-linked Factors in Drosophila.—There is abundant substantiating proof of this theory from the behavior of sex-linked factors. The sex chromosomes carry factors that determine characteristics just as do the other chromosomes. The factor for white eyes in Drosophila, for instance, is sex linked. When a white-eyed male rXY is mated to a red-eyed female RX RX, the F_1 offspring all have red eyes, because red eye is dominant to white eye in Drosophila. In F_2 red- and white-eyed flies are produced in the proportion of 3 red:1 white. All the females of this generation are red-eyed, but of the males half have red eyes and half have white eyes. When the reciprocal cross is made, *i.e.*, when a white-eyed female is mated to a red-eyed male, the results are different. In the F_1 of such a mating all the female

flies have red eyes and all the male flies have white eyes. In F_2 of this cross, half the females have red eyes and half have white eyes, and likewise among the males, half have red eyes and half have white eyes.

	rX	Y
RX	$RX\ rX$	RXY
RX	$RX\ rX$	RXY

F_1 cross white-eyed male and red-eyed female

	RX	Y
rX	$RX rX$	rXY
rX	$RX\ rX$	rXY

F_1 cross red-eyed male and white-eyed female

	RX	Y
RX	$RX\ RX$	RXY
rX	$RX\ rX$	rXY

F_2 cross white-eyed male and red-eyed female

	rX	Y
RX	$RX\ rX$	RXY
rX	$rX\ rX$	rXY

F_2 cross red-eyed male and white-eyed female

FIG. 51.—Diagram of cross of white-eyed male × red-eyed female and its reciprocal.

In the above diagrams the presence of two X chromosomes determines a female, an X and a Y chromosome determine a male. The presence of at least one capital *R* determines red eyes, because red eye is dominant to white. It has been pointed out previously that, aside from the pair of sex chromosomes, the pairs of chromosomes in both the male and the female of Drosophila are alike and carry corresponding factors or determiners of characteristics. In the male, however, the Y chromosome appears to have no effect upon the development of the body characteristics, so that the male depends upon a single X chromosome for the factors born in this chromosome. The Y chromosome may, therefore, be regarded as a neutral mate for the X chromosome in the male.

Sex-linked Factors in Man.—In the human family a sex-linked characteristic is that of color-blindness, or the inability, through some inherent defect in the eye, to distinguish between red and green. It is well known that there are many more color-blind men than women, the reason for which should soon be evident. Representing normal vision with large *B* and color-blindness with small *b*, the following is the genetic make-up of a normal-visioned woman *B*X *B*X and of a color-blind man *b*XY. Such mating would give children in F_1, all which would be normal-visioned, though all the daughters would be carriers of color-blindness. In F_2 there would be three normal-visioned children (two

daughters and one son) to one color-blind child (son). The reciprocal cross is also diagrammed below.

	bX	Y
BX	$BX\ bX$	BXY
BX	$BX\ bX$	BXY

F_1 cross color-blind man and normal-visioned woman

	BX	Y
BX	$BX\ BX$	BXY
bX	$BX\ bX$	bXY

F_2 cross color-blind man and normal-visioned woman

	BX	Y
bX	$BX\ bX$	bXY
bX	$BX\ bX$	bXY

F_1 cross normal-visioned man and color-blind woman

	bX	Y
BX	$BX\ bX$	BXY
bX	$bX\ BX$	bXY

F_2 cross normal-visioned man and color-blind woman

FIG. 52.—Diagram of cross of color-blind man × normal-visioned woman and its reciprocal.

In the above, two X chromosomes determine a female, an X and a Y chromosome determine a male, and at least one large *B* determines normal vision. The occurrence of color-blind men is to be expected twice as frequently as is that of color-blind women.

Non-disjunction in Drosophila.—An aberrant type of reduction in Drosophila, occurring very rarely, lends support to the chromosomal interpretation of sex determination. This is the feature of non-disjunction which has been worked out by Bridges. This investigator has shown that occasionally reduction in the germ cells takes place in such a way that after synapsis the two sex chromosomes of a female do not disjoin but both of them pass to one pole of the cell, giving rise to daughter cells of the constitution XX and O instead of two normal daughter cells each containing one X chromosome. The relations holding may be made more clear by means of introducing a sex-linked character. If, for instance, a white-eyed female ($rX\ rX$) is mated to a red-eyed male (RXY), all the normal daughters will be red-eyed and the normal males white-eyed.

	rX	rX
RX	$RX\ rX$	$RX\ rX$
Y	rX Y	rX Y

If, however, in a white-eyed female non-disjunction occurs, individuals of the four types indicated in the diagram below should be produced.

	$rX\ rX$	O
RX	$RX\ rX\ rX$	RX O
Y	$rX\ rX$ Y	Y O

As a matter of fact, the RX rX rX individuals die, as do also the YO individuals, the former, as Morgan suggests, because of too many X's and the latter presumably because of not enough X's. To survive, an individual must have either one or two X chromosomes—no more and no less. The other two individuals rX rXY, a white-eyed daughter, and RXO, a red-eyed male, are the exceptions to the normal expectancy.

Breeding results from such individuals in F_2 (which the student can diagram) give results that would be expected from individuals of such a chromosomal make-up and the point to be stressed here is that, in either F_1 or F_2 individuals, two X chromosomes result in producing a female and one X chromosome a male.

These results not only furnish very strong proof of the chromosome theory of sex, but serve also to show how a knowledge of the actual mechanism involved leads to the discovery of how a change in the mechanism gives a new output. The conclusion that females behaving in this manner must contain a Y chromosome was confirmed by the cytological demonstration that showed in them two X's and a Y [1]

The distinguishing feature of the XY type of sex inheritance which prevails in mammals is that the female is homozygous and the male heterozygous for the sex chromosome.

WZ Type of Sex Inheritance.—Another type of sex inheritance, which, to distinguish it from the XY type, is called the WZ type, is found in poultry. Here the distinguishing feature is the fact that the male is homozygous for the sex chromosome, while the female is heterozygous. According to Castle, this condition is found in moths and in certain birds, *viz.*, in domestic fowls, pigeons, ducks, and canaries.

A well-known example of sex-linked inheritance in poultry is that of coat pattern. For instance, if a Plymouth Rock (barred) cock is mated to a black (or any other non-barred breed), the F_1 offspring, both male and female, are barred. When these F_1 hybrids are mated, producing the F_2 generation, there result three barred individuals (two males and one female) to one non-barred or black (female). When the reciprocal cross is made, *viz.*, black cock mated to barred hens, there are produced in F_1 barred males and non-barred or black females. When these F_1 hybrids are mated, producing the F_2 generation, half the number of males

[1] Morgan, T. H., The physical basis of heredity, p. 203, J. B. Lippincott Company, 1919.

so produced are barred and half are black, and of the females half are barred and half are black. Diagrammatically, we have *B*, barred; *b*, black; WW, male; WZ, female.

	BW	*BW*
bW	*BW bW*	*BW bW*
Z	*BWZ*	*BWZ*

F_1 cross barred cock and black hen

	bW	*bW*
BW	*BW bW*	*BW bW*
Z	*bWZ*	*bWZ*

F_1 cross black cock and barred hen

FIG. 53.—Diagram of cross of barred cock × black hen and its reciprocal in F_1.

	BW	*bw*
BW	*BW BW*	*BW bW*
Z	*BWZ*	*bWZ*

F_2 cross barred cock and black hen

	BW	*bw*
bW	*BW bW*	*bW bW*
Z	*BWZ*	*bWZ*

F_2 cross black cock and barred hen

FIG. 54.—Diagram of cross of barred cock and black hen and its reciprocal in F_2.

In the above, two W's determine a male, one W and one Z a female, and at least one large *B* a barred individual.

In neither the XY nor the WZ type does crossing over take place in the individuals heterozygous for the sex chromosome.

Sex Determination in Cattle.—Through the very excellent work of Wodsedalek the fact has been quite firmly established that in cattle sex is determined by a definite factorial condition in the chromosomes of the germ cells. Through the coöperation of a packing plant this investigator was able to secure a great deal of testicular and ovarian tissue as well as numerous fetuses in varying stages of development. Slides were made of this material and many important cytological facts established.

The number of autosomes in cattle is thirty-six in both the male and female. The primary male germ cells (spermatocytes) always contain one large chromosome, often termed the nucleolus. This is a sex chromosome. When secondary spermatocytes are produced, half of them have eighteen autosomes plus the nucleolus or sex chromosome and the other half have only the eighteen autosomes. These give rise to spermatids and eventually spermatozoa, half of which have a sex chromosome, half of which do not. Measurements of the head length of some 600 spermatozoa yielded a bimodal curve with modes at 12.5 and 14.75 millimeters.

The intermodal depression was deep and wide and the two elements of the curve were approximately equal as regards number of individuals. The spermatozoa of the large type undoubtedly possess the sex chromosome, while those of the small type were without it.

The oögonia or primary oöcytes studied always exhibited two large nucleoli or sex chromosomes as well as the thirty-six auto

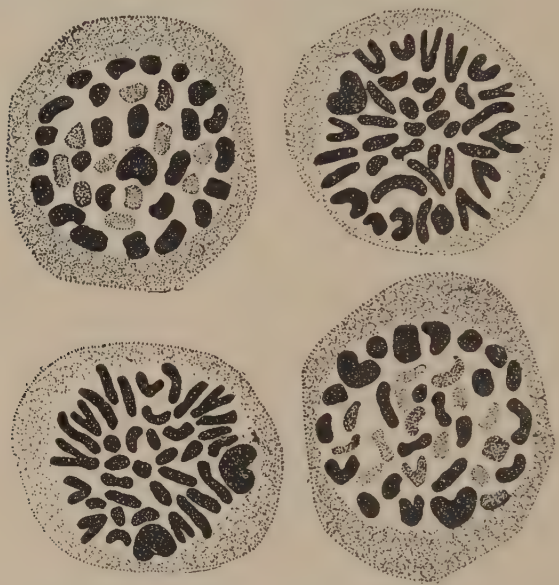


FIG. 55.—Upper left, liver cell from male; upper right, brain cell from male. Lower left, brain cell from female; lower right, liver cell from female. These cells were secured from embryos and show 36 autosomes in each, plus 1 sex chromosome in the cells from male embryos and 2 sex chromosomes in cells from female embryos. (*Photo from Wodsedalek.*)

somes. In normal reduction, therefore, all of the ova produced must necessarily have eighteen autosomes and one sex chromosome.

Since the two types of spermatozoa are produced in equal numbers, fertilization by the one kind or the other is equally possible, and the number of the male and female calves born is about equal, if a fairly large number of offspring is considered. Sex in the offspring, as determined at the time of fertilization of the ovum by the one or the other type of spermatozoön, may be illustrated as follows:

SPERMATOZOA		OVA		OFFSPRING	
(18 + 1)	+	(18 + 1)	=	(36 + 2)	Female
(18 + 0)	+	(18 + 1)	=	(36 + 1)	Male

The results of the above combinations are in exact accord with the number of chromosomes found in the germinal and somatic cells of the two sexes in cattle . . .

Numerous slides were made of various somatic structures from fetuses of both sexes. The organs most frequently used were the brain, lung, liver, Wolffian body, kidney, and intestine. The larger embryos were cut into pieces, all of which were then sectioned. Three small embryos, ranging from 10- to 14-millimeter neck lengths were sectioned in *toto*. While splendid mitotic figures and late prophase stages were found in many parts of the embryos, the very best cells were found in the brain. In the larger specimens the liver and kidneys showed the most favorable cells.

The *male somatic cells*, like the spermatogonia, *contain thirty-seven chromosomes*, of which thirty-six are the ordinary chromosomes and one is the accessory element or sex chromosome. The female somatic cells, like the oögonia, contain thirty-eight chromosomes, of which thirty-six are the ordinary chromosomes and the other two are the sex elements. The sex chromosomes in each case were as distinguishable as they are in the germinal cells. Literally thousands of somatic cells were carefully studied in each sex.[1]

Mammals of XY Type.—From the preceding section it will be seen that determination of sex in cattle is of the XY type. In this species the female carries two X chromosomes and the male but one, differing from the chromosome mechanism where the male has one X and one Y chromosome. In either case there will be two sorts of spermatozoa produced; in Drosophila, one X-and one Y-chromosome type; in cattle one X-chromosome type and one with neither an X nor a Y chromosome, but an O-chromosome type. In both cases the female is homozygous for the sex chromosome, all the ova containing an X chromosome, the sex of the resulting individual depending upon the type of spermatozoön that fertilizes the ovum. All mammals are of this XY type of sex inheritance, *i.e.*, female homozygous.

Metabolic Theories of Sex Inheritance.—The greatest opposition to the chromosomal explanation of sex determination has come from the adherents of the metabolic theory. It will be recognized that the former is a morphological while the latter is a physiological explanation. The metabolic theory states that a preponderance of katabolic processes determines maleness and of anabolic processes femaleness. It is well known that the

[1] Wodsedalek, J. E., Studies on the cells of cattle etc., *Bio. Bull.* **38** (5): 300, 1920.

state of nutrition does exert a profound influence upon the body in general and it is entirely conceivable that it might also affect the reproductive organs. That is, the state of nutrition may have an influence on the relative number or vitality of the X or O type spermatozoa produced in mammals or of the W and Z type ova produced in fowl. This, however, in no way invalidates the morphological interpretation of sex determination. It is only when the adherents of the metabolic theory argue for the possibility of changing sex after it has once been established by the union of a certain ovum and a certain spermatozoön that their hypothesis seems questionable.

Nevertheless, Riddle claims to have absolutely controlled sex determination in the pigeon by experimental means. Having learned to identify the male- and the female-producing ova, he was able, he says, to force either kind into the production of the opposite sex and he noted that the level of its metabolism was then shifted to the level characteristic of the germs of the opposite sex. Thus chromosomal correlation is here forced to failure but the metabolic correlation persists. Riddle infers, therefore, that the chromosomal constitution is not an efficient cause of sex; that it is but a sign or index and possibly an assistance in the normal maintenance of that which is essential—namely, two different metabolic levels.[1]

An authentic case of sex reversal has been reported from Edinburgh University, Scotland. A three-and-a-half-year-old Buff Orpington hen which had raised several broods of her own chickens

. . . began to suffer from disease of the ovary; the ovarian tissue was progressively destroyed, and the effects of this pathological castration were seen. But the conditions which were created were those favorable for the differentiation and growth of spermatic tissue. The bird became anatomically equipped to function as a male and actually became the father of chickens. Under these circumstances, in which a "determined" female becomes a "somatic" male as a result of a definite change in its metabolism, it would be expected that the proportion of the sexes among its offspring would be one male to two females. Of the two chickens one is a male, the other a female; they have been mated, and their offspring are typical Buff Orpington chickens.[2]

[1] Babcock and Clausen, Genetics in relation to agriculture, 545 pp., McGraw-Hill Book Company, Inc., 1918.

[2] Crew, F. A. E., Animal genetics, pp. 241–242, Oliver & Boyd, 1925.

The free-martin, a heifer born a twin with a bull, is often cited as a case of sex reversal, *i.e.*, that originally there were two bull calves and that through a change in metabolic level one of these bulls is changed to a heifer or nearly so. Lillie's extensive work on the free-martin, however, has apparently proved that the phenomenon evidenced by the free-martin is brought about by means of fetal vascular anastomosis in the two embryos, which gives the testicular hormone of the male access to the female embryonic circulation where it affects a retardation of normal development of the female reproductive organs. This refutes the idea of sex reversal as a means of explaining the free-martin.

There is little indication and no sure proof of sex reversal in mammals. With the different metabolic levels that may be experienced by a female during a long gestation period, it would seem improbable that facile interference in such a vital consideration for perpetuation as sex would be possible.

Conditions Influencing Sex Ratio.—The weakness of the sex-reversal position does not mean that internal or external conditions may not have a vital influence on the sex ratio. Thus Jull reports in poultry a sex ratio, based upon annual production, of 48.41 ± 0.47 and for the normal hatching season, March and April, of 48.82 ± 0.80. The same investigator also furnishes the following table:

TABLE XIV.—SEX RATIO OF PULLET EGGS FOR EACH SERIES OF 20 EGGS

EGG PRODUCTION	SEX RATIO[1]
0– 20	62.91 ± 1.44
21– 40	57.46 ± 2.88
41– 60	45.00 ± 2.04
61– 80	44.61 ± 0.69
81–100	37.65 ± 1.00
101–120	32.53 ± 1.15

[1] This sex ratio is based on fifty females (from Jull).

It will be seen from the above table that an early tendency in pullets to produce a preponderance of males gradually shifts over as egg laying proceeds to a tendency to produce a preponderance of females. Discussing these results Jull says:

Since in the domestic fowl the male is homozygous for sex, it does not seem probable that the spermatozoa would influence the situation. It is apparent that increased egg production must bring about certain changes in the eggs, so that more and more females are produced as egg laying advances. There was no indication of sex reversal, since a

positive check was used to test this possibility. Brown Leghorn males were mated to Barred Plymouth Rock females and the male progeny were barred and the female progeny were black. All the available evidence points to the conclusion that the different sex ratios occurring in the different periods are due to differential maturations in the egg. Apparently, among the first eggs laid the female-producing chromosome complex is extruded as a polar body more frequently than the male-producing complex, and as egg laying continues the male-producing complex tends to be extruded, as a polar body more frequently than the female-producing complex. This tendency for the extrusion of one kind of chromosome complex in preference to the other at different stages of egg production is probably due to differences in the chemical composition of the eggs in early as compared with late laying. The differences in the chemical composition give rise to different reaction systems within the reproducing cell.[1]

Results somewhat similar to those of Jull were obtained by Hays in an experiment to test the effect on the offspring of very frequent service by the male rabbit. In this species the male is heterozygous for sex and, just as with Jull's poultry, where the increased functional activity of the ovary tended to produce a swing to a lower sex ratio, so also with Hays' rabbits the increased functional activity of the testicle tended to produce a swing to a lower sex ratio.

The following tabulation makes this clear:

	Service				
	First	Fifth	Tenth	Fifteenth	Twentieth
Sex ratio.....	56.33	43.50	44.44	34.64	21.87

Hays offers two explanations of the above lowering of the sex ratio: (1) that there may be an increase of female-producing spermatozoa as the burden of service increases, (2) that the male-producing spermatozoa become weaker with increasing service. The former of these explanations is opposed to the accepted view as to the manner in which the reduction process produces an equality of two kinds of spermatozoa in mammals. The second explanation seems the more probable, because the increased func-

[1] Jull, M. A., Can sex in farm animals be controlled? *Prac. Amer. Soc. for An. Prod.*, 96 pp., 1922.

tional activity of the secreting tissue of the testicle could very well bring about, through its chemical processes, a changed rate of metabolism. The explanation in both fowl and mammal is to be sought in terms of the chemistry of the ovaries and testicles —in other words, it probably is metabolic.

Effect of Selection on Sex Ratio.—King's work with the albino rat illustrates the way in which selection may influence the sex ratio. This investigator, starting with two pairs of rats from the same litter, has inbred litter brother and sister for twenty-five generations. With no selection from a sex standpoint in the first six generations, the sex ratio was 108.6 compared to a norm of 105. After the sixth generation selection was made along two lines, namely the *A* line taken from litters that produced an excess of males and the *B* line taken from litters that produced an excess of females.

The sex ratios were as follows:

TABLE XV.—SEX RATIOS IN KING'S INBRED RATS

A-line females × *A*-line males	122.3
B-line females × *B*-line males	81.8
A-line females × stock males	115.6
B-line females × stock males	91.1
Combined data for the two inbred lines	102.7
Stock females × *A*-line males	102.3[1]
Stock females × *B*-line males	96.2[1]

[1] Not significant statistically, according to King.

These results indicate that the sex ratio may be changed by selection, inasmuch as the straight inbred lines *A* and *B* differ from the norm by 17.3 and 23.2 points respectively. Since the inbred females of the *A* and *B* lines mated to stock males differ from the norm by 10.6 and 13.9 points respectively, while the inbred males of the *A* and *B* lines mated to stock females differ from the norm by 2.3 and 8.8 points respectively, it would seem that the changed ratio was to be laid at the door of the female rather than that of the male. King says:

> The results in this case, therefore, do not indicate that inbreeding, with selection, influences the potency of the spermatozoa in any way; they seem rather to signify that the particular stock females used for breeding tended to attract spermatozoa that were "female producing" rather than those that were "male producing" . . . An earlier experiment that has a bearing in this connection seems to have been

overlooked and therefore needs to be noted here. Marshall (1910) injected into the vagina of a purebred Dandie Dinmont bitch a mixture of seminal fluid taken from a purebred dog of the same species and from a mongrel terrier of unknown ancestry. Fifty-nine days later the bitch littered, producing four pups which were much alike. One of the pups died early, but as the other three developed into mongrels which resembled the terrier sire, there was little doubt but that all four puppies were mongrels. Marshall cites another case in which a Dandie Dinmont bitch copulated with a dog of the same breed and two days later with a Scotch terrier. The bitch littered three pups; one was pure Dandie Dinmont, the other two half-bred Scotch terriers. These cases, according to Marshall, were indicative of a "selective" on the part of the ova of the purebred bitch to "conjugate with dissimilar rather than with related spermatozoa."

I have recently been making a series of experiments somewhat on the order of those cited by Marshall, and the results obtained indicate a very strong tendency on the part of the ova of the albino rat to conjugate with spermatozoa from the wild gray rat rather than with the spermatozoa of the albino rat, although, under the conditions of the experiment, details of which will be published later, the advantage in every case was with the spermatozoa from the albino male. If fertilization can be selective in such cases I can see no valid objection to the assumption that the chemotactic reaction between ova and spermatozoa may be even more delicate and thus, under given conditions, make possible the fertilization of an egg by spermatozoön that has one sex potency rather than the other . . .

The anomalous sex ratios that appear in F_1 hybrids almost invariably show an excess of males. This suggests that the greater the difference between individuals as regards their blood relationship the stronger is the attraction between the ova and the "male-producing spermatozoa." If this suggestion proves true, its converse ought also to be true, and in a closely inbred line we would expect that the chemotactic reaction between the ova and the spermatozoa would be such that an excess of females would be produced. Such a possibility is not incompatible with the results of the present investigation, since in the inbred strain, as a whole, the sex ratio was below the norm, while the sex ratios in the litters of the female line showed a greater deviation from the norm than did the sex ratios in the litters of the male line.

The results of this series of experiments, as a whole, seem to indicate that in the rat, as in the pigeon (Riddle, 1914, 1916, 1917), in Drosophila (Moenkhaus, 1911), and in the guinea pig (Papanicolau, 1915), the female has more influence in determining the sex ratio than has the male. Yet it is not in the differentiation of the ova, nor in the development of the spermatozoa, that the key to the riddle of sex determination will be found. A knowledge of the interaction of the germ cells, and

of the conditions that influence it, must be gained before the final solution of this problem can be attained.[1]

Any livestock breeder can cite instances of certain individuals, both male and female, that have tended to produce offspring preponderantly of one or the other sex. At the National Dairy Show of 1923, there was exhibited Financial King's Interest a twenty-three years' and nine months' old Jersey cow that had produced 21 calves, 20 heifers, and 1 bull. The records at the Massachusetts Agricultural College show a Guernsey bull that left 28 bulls and 14 heifer calves, a Holstein that left 26 bulls and 19 heifers, an Ayrshire that left 18 bulls and 7 heifers, and a Jersey that left 11 bulls and 6 heifers. These are the most extreme cases that can be found in this dairy herd over a period of about fifteen years. Among the cows 3-7, 2-6, 7-0, 7-1 and 7-2 combinations are the most extreme. The cows, as a whole, have produced 471 male and 452 female offspring and the bulls 440 males and 419 females.[2] Experience teaches that certain animals do tend to drop a preponderance of one sex or the other. Perhaps this has a definite factorial basis which can be modified by selection.

Conclusion Regarding Sex Determination.—The work herein reported seems to justify the conclusion that in mammals sex is determined by the type of spermatozoön that fertilizes a given ovum, and the paucity of knowledge concerning the factors that determine just what spermatozoön shall fertilize a given ovum must be admitted. It no doubt depends upon the chemical attraction between spermatozoa and ova. Those who argue that sex is dependent on the male are partly right, because the differentiation in mammals occurs in the male, and those who argue that sex is dependent on the female are partly right, because the ovum does, no doubt, attract some spermatozoa more strongly than others, which tendency can no doubt be enhanced through selection. Unquestionably, chemical changes which affect the sex ratio do occur in both spermatozoa and ova, and the solution of the problem will result from a more thorough knowledge of both sexes, as, no doubt, they both exert large influence.

[1] King, Helen Dean, "Studies on Inbreeding," pp. 130–133, Wistar Institute, Philadelphia, 1919.

[2] The greater number of offspring for the cows is due to the fact that in some cases the bull was unknown.

Sex Control.—Conceivably, there can be no sex control until the normal functioning that determines sex is fully understood. It is premature to speculate on sex control until the fundamental problem has been solved. When the chemistry of the germ cells is known, it seems very possible that through the aid of chemistry, possibly serology, and the device of artificial insemination, one may be able to bring about the production of males or females at will. From a breeding standpoint this would have very marked advantages over the present system of trusting to luck.

CHAPTER XIV

GRADING AND CROSSBREEDING

The system of breeding to be adopted is one of the most important problems that a breeder has to solve and requires much study and thought if it is to be properly adjusted. There are five systems of breeding, namely, grading, crossbreeding, outcrossing linebreeding, and closebreeding each of which has merit under given conditions. The variables in the problem are numerous and must all be properly appraised before ultimate success can be achieved. This chapter will deal with the simpler systems of breeding, namely, grading up, crossbreeding and outcrossing.

Grading Up.—By common usage, at the present time, "grading" refers to the practice of using a purebred sire of any breed on native or grade females. When followed through to its logical conclusion, always using good sires of the same breed, it is a practice to be highly commended. Its purpose is to develop uniformity and to increase productivity and quality in the offspring. The pure breeds are generally capable of producing these results because they have been selected for many generations for particular points and purposes within rather narrow limits and specifications. This does not mean that a purebred will necessarily effect an improvement when bred to grade animals, for, unfortunately, as is quite generally recognized, there are even at the present time a goodly number of inferior purebreds. The average purebred, however, will help to bring about uniformity and to increase productiveness in the average grade herd and can be used for this purpose. The first-generation offspring will carry 50 per cent of pure "blood." When these are, in turn, mated to another purebred sire of the same breed, the resulting offspring will carry 75 per cent of pure "blood" and so on. After five or six top crosses of this sort, where one breed has been adhered to for the sires, the animals are to all intents and purposes purebred, though they are not eligible to registration. This is because the pure breeds have certain definite distinguishing characteristics which breeders do not want to see disturbed.

Such might occur if five or six top-crossed grade animals were admitted to registry, it being possible and probable that the grades would be carrying along in a recessive condition in their germplasm undesirable characteristics which would, at some future time, crop out in the herd.

Grading Best System for Beginners.—It seems logical to advise the average man starting in the livestock business to start with the system of grading. It will be admitted at once that this system leaves something to be desired, but it must also be admitted that it has its advantages. The most important consideration is, no doubt, that of cost. With grades, a start can be made for considerably less money than would be required for purebreds. Breeders of purebreds are coming to recognize that this practice is sound and advantageous to them. This plan will furnish a market for all a breeder's males and for his relatively few females, most of which he will need to keep and test. It will mean more business eventually for breeders of purebreds to have beginners start with a grade herd and a purebred sire and later, when they have learned something of the business and become established, change over to a purebred herd. If beginners are induced to start with purebreds, the herd must be a small one, because usually the capital at hand is limited and the opportunity for eventual success and growth in the business is thereby greatly curtailed. Many men have started with purebreds, have soon become discouraged, and either have gone back to grades or have gone entirely out of the business. Besides the greater initial cost of starting with purebreds, there is another influence to consider, namely, that when a man has invested in purebreds he is quite apt to think that he ought either to sell at rather high prices or to retain in his own herd all of his herd increase as breeding stock. This is an element that hurts the purebred breeding business in many ways. In the first place, all the increase of these herds is not capable of improving the breed, and a part of it should go to the shambles. The average man will not hesitate to send surplus off-type grade offspring to the butcher, but it takes more courage than some men possess to see the offspring of purebreds, for which they have paid considerable money, going that way. For purely productive purposes, a herd of good grade animals, headed by a good purebred sire, is just as efficient and will make the owner as much money as a herd of purebreds.

For the young breeder it is a serious question whether to start with purebreds or grades. Many arguments can be advanced on both sides, and in the final analysis it is a matter to be settled individually. It would no doubt often be possible to start with

Scrub cow No. 60 average production 3,313.2 lb. of milk and 178.47 lb. of fat.

Half-blood Jersey No. 241 out of scrub No. 60. Average production 6,126.4 lb. of milk and 348.98 lb. of fat.

Three-quarter blood Jersey No. 348 out of half-blood Jersey No. 241.

FIG. 56.—Showing results of grading up. (*Photo from Iowa Agr. Exp. Sta. Bull.* 188.)

somewhat old, time-worn purebreds about as cheaply as with grades. A prospective breeder might find that he could secure individuals that were growing old, cows with only three good quarters, etc., for the same prices he would have to pay for grades.

If such animals were of *good blood lines,* had a reasonable prospect of producing a few more offspring, and could still produce enough so that they would yield a little more than their keep cost, they no doubt would prove to be profitable investments. Young breeders of limited means who plan eventually to have purebreds can well consider this and somewhat similar plans for getting good "blood," good germ cells at reasonable prices.

FIG. 57.—The grade Clydesdale gelding, Major MacFarlane, champion at the International 1921 and 1923. He is only two generations removed from a Cayuse mare.

Results of Grading.—McCandlish, Gillette, and Kildee, at the Iowa Agricultural Experiment Station, graded up a herd of scrub cows with purebred sires of the dairy breeds. The first-generation grades produced 55 per cent more milk and 44 per cent more fat than their dams, and the second-generation grades produced 116 per cent more milk and 106 per cent more fat than their scrub granddams, due to the fact that these cows not only produced more milk, but had longer lactation periods, things for which the purebreds have been selected for a great many generations. The champion gelding at the International Live-

stock Exposition in 1921 and 1923, Major MacFarlane, was a grade horse two generations removed from a Cayuse or Indian pony mare. The thousands of purebred beef bulls that have been used on the cattle of the western ranges during the last half century have graded up these herds and greatly improved the quality of the carcasses produced. It is in this field, the grading up of the common herds and flocks, that scientific breeding and far-sighted breeders can wield a great influence. The Government's recent purebred-sire campaign has been very well received by breeders and farmers and will doubtless greatly increase the average and total value of livestock in the United States.

Crossbreeding.—The next system of breeding to consider is that of crossbreeding. By this term is meant the crossing either of species or of breeds within a given species. Common examples of this type of breeding are the mule, a species cross (the resulting animals usually termed *hybrids*), and the blue grays (Angus and Shorthorn), a breed cross such animals being spoken of as *crossbreds*. Crossbreeding brings together more or less divergent sorts of germplasm, which gives rise to variations, especially in the F_2 and subsequent generations. In this, as well as in the matters of size, vigor, and fertility, one or more of which crossbreeding usually increases, it is the opposite of closebreeding. Crossbreeding has both desirable and undesirable features.

Crossbreeding for the Market.—Crossbreeding is used to a considerable extent in the production of meat animals, because crossbred animals usually show an increase in growth and vigor over either one of their purebred parents. The exact cause of this phenomenon is not known, though some authorities suggest that it may be due to the fact that all breeds or varieties carry in the germplasm, along with their desirable characteristics, some inhibiting characteristics and that in crossbreeding these inhibiting factors in each species or breed are neutralized by factors from the other species or breed. The term given to this feature is *hybrid vigor* or *heterosis*. At any rate, it is proved that the animals resulting from such crosses are usually more vigorous. The mule is highly prized for this very feature, being tough, vigorous, hardy, and because of its lighter weight requires less feed for maintenance than does the horse. Generally speaking, the mule is not quite so fastidious as the horse, but when properly treated and trained it is fully as tractable and faithful. As noted above, this system is very often used in the production of meat animals.

Some of the grand champion steers at the international livestock show have been crosses among Herefords, Angus, Shorthorns, and Galloways. California Favorite, the grand champion in 1916, was a crossbred Shorthorn-Hereford and was reputed to have been one of the finest steers ever exhibited. This system of cross-breeding is also often used for the production of high-quality pork. In such crossing it is desirable to select the sows from a

FIG. 58.—California Favorite, the Grand Champion steer at the 1916 International Livestock Exposition. The steer was out of a red Shorthorn cow and by a Hereford bull. (*Photo. from Genetics in Relation to Agr. Babcock & Clausen.*)

breed known for its prolificacy, as the boars of any breed should furnish a superabundance of spermatozoa. Crossbred hogs are extremely vigorous and rapid growers; whether there is any economy in amount of feed necessary to produce 100 pounds of pork has not been demonstrated, though there is no reason to suspect inefficiency in this respect. Many middle-wool and long-wool rams have been used on the Merino flocks of the West in order to increase the size and quality of the lambs from a meat standpoint.

Crossbreeding and New Breeds.—Crossbreeding with its attendant variation plus later painstaking selection has been used for the creation of several new breeds. In sheep, one of the breeds, namely, the Oxford Down, is the direct result of crossbreeding, the Cotswold and Hampshire Down furnishing the pure breeds for the cross. This crossing, followed by rigid selection for specific points and type, has established the Oxford Down as a pure breed. Corriedale, a New Zealand breed of sheep, resulted from the use of Leicester and Lincoln rams or Merino ewes, and the Columbia breed was perfected by the specialists of the U. S. Department of Agriculture, using the Lincoln and Rambouillet breeds. The U. S. Government, with the coöperation of the state of Wyoming, is at the present time carrying on a crossbreeding experiment with horses, using the American standardbred horse, the Morgan, and the American saddle horse in judicious crosses, attempting to create an American utility horse that will combine in one breed

> . . . size, substance, soundness, endurance, good temperament, well-balanced action, and a fair amount of speed at the walk and the trot. If these qualities can be incorporated in a breed of horses without the infusion of draft blood, the result will be a utility horse which can perform the many odd jobs on the farm, on the road, under the saddle, and, in cases of national emergency, on the battlefield.

Lamonia, a new breed of poultry, has recently been created by crossbreeding. Leghorn, White Plymouth Rock, and Dorking were the breeds used in founding Lamonia, which combines the characteristics of good production, a white-shelled egg, and desirable type for meat.

It should be possible through crossbreeding to establish new breeds with any desired combinations of characters, unless, of course, the latter are antagonistic to each other or linked in such a way in the germplasm that segregation is impossible. The drawbacks to this procedure are serious ones, however, because of the time and expense involved and the large number of animals that must be produced in order to give ample range for selection. After these difficulties have been overcome, there would still remain even a greater one, namely, selling the new breed to the breeders and growers. The breeds as they exist today seem to fill most of the needs fairly well, and it would be a colossal task requiring a vast outlay of money to make room for a new one, though some day it may be done.

This whole matter of the possible creation of superior new breeds in any and all classes of livestock is an extremely fascinating one and is fraught with tremendous possibilities, though it is not a field in which an ordinary breeder with limited time, capital, and number of animals can hope to achieve success. He lacks the necessary equipment. If exploited at all, these fields should be left to the state agricultural experiment stations or the U. S. Department of Agriculture.

Various Commercial Hybrids.—The mule is at the present time the best-known hybrid in the United States. The mule is the result of crossing a jack (male of the ass family) on a mare (female of the horse family). This cross has been valued for many centuries. Fertile mare mules have been reported at various times, but the reports have never been capable of absolute verification. In 1920, however, L. T. Branham of Montalla, Tex., reported that a mare mule in his possession, which had been bred to a jack, had dropped a living foal. The contention was supported by affidavits of the owner and some neighbors. The mare was loaned to the Texas A. & M. College and after failing to conceive when bred to a jack in 1921 she dropped a living stallion colt in 1923 as the result of being mated to a saddle stallion the year previous. This case appears authentic, though it is difficult to explain, since the characteristic number of chromosomes in the horse family and in the ass family is different. The mule approximates more closely to the ass than to the horse in general characteristics.

The hinny is the reciprocal of the mule, being the result of a stallion-jennet cross. It more closely approximates the horse in general characteristics. The hinny has never become popular nor numerous.

The zebroid, a zebra-horse hybrid, is fairly popular in the tropics because of its docility and its resistance to disease and the effects of the heat.

Several hybrids in the genus Bos are fairly common. Of these one of the best-known and most valuable results from crossing the zebu, or humped variety of cattle, on ordinary cattle. Heterosis is evidenced and the zebu's resistance to ticks, fever, and various diseases is at least partially dominant. This cross is quite common in Brazil and seems to be gaining in popularity in the southwestern part of the United States, especially in Texas.

Bison and cattle belong to the genus Bos and are interfertile. Bison bulls are bred to domestic cows to produce this cross. Males are seldom born alive, due either to their height back of the shoulders, which prevents their passing through the cow's pelvis, or to too great a quantity of allantoic fluid, and seem never to be fertile. Some of the females are fertile. The first cross, bison bull on domestic cow, is called a hybrid or half-bred buffalo. The second cross is made by using a domestic bull on the above hybrid. The females resulting from this cross are mated to bison bulls and the offspring are termed cattaloes. Besides more rapid growth and greater vigor the following advantages over cattle are attributed to the cattalo, namely, greater resistance to many diseases, including black leg and Texas fever, higher dressing per cent, failure to run from heel flies and to drift in storms, lower feed requirement, and a greater ability to withstand lack of water.

Disadvantages of Crossbreeding.—Crossbreeding also has its disadvantages, and they are serious ones. In the first place, if a man is to crossbreed, it means that he must keep two or more pure breeds in order to produce the crossbreds. This involves a considerable investment, as rapid progress need not be expected in any line of breeding unless sufficient numbers can be kept to allow for rigid selection. Another even more serious disadvantage in the field of crossbreeding is the fact that most breeders cannot resist the temptation to use some particularly good crossbred animal for breeding purposes. The crossbred may have all the distinguishing characteristics of a purebred, be capable of more rapid growth as well as being more vigorous, but no crossbred animal, particularly a male, should ever be used for breeding purposes. The reason lying back of the last statement is that the crossbred animal, due to the nature of its origin, cannot produce a uniform set of offspring, because it cannot produce a uniform set of germ cells. It will be recalled that determiners for the various characteristics separate or segregate out independently of each other unless, of course, they are located in the same chromosome under which condition they tend to stay linked together. This independent segregation and recombination produces a wide range of variation—dissipates uniformity. Heterosis or hybrid vigor exhibited by crossbreds is not continued in future generations of their offspring. It may be concluded, therefore, that crossbreeding for purposes of producing superior

stock for slaughter is a desirable thing for breeders who can maintain fairly large herds of the purebreds; that the system has possibilities for the creation of new breeds embodying groups of characteristics now found individually in two or more; and that only under the latter conditions, probably in the hands of government or agricultural experiment station experts, should the crossbreds be used for breeding purposes. Crossbreeding is also an extremely useful tool for the study of the behavior of characteristics in hereditary transmission.

Outcrossing.—Outcrossing is the mating of animals within a given breed which are not related, at least show no relationship in the first six or eight generations of their pedigrees. It is a more or less hit or miss system of questionable merit but nevertheless it is in wide use. It is probably true that the majority of animals are the result of outcrossing. The mating of unrelated animals sometimes results very favorably to be sure but it is also a fact that most breeders who achieve distinction do so by (1) securing desirable animals of certain strains or families in their particular breed and (2) intensifying the good characteristics of these animals through close- or linebreeding. Nevertheless the master breeders at times have recourse to outcrossing for its regenerative effect or for the purpose of introducing new characteristics. Only when used in these latter ways with a specific aim in view is outcrossing to be commended.

CHAPTER XV

INBREEDING

Diverse opinions are held regarding the practice of inbreeding. Speaking generally, it is in bad repute, because it is believed to result in a more or less degenerate offspring. There can be no doubt, however, that many cases of improvement have also resulted from its use.

At the outset it is quite essential to define just what is meant by inbreeding. Inbreeding is evidenced when any ancestor appears more than once in a given animal's pedigree. Inbreeding is divided into two categories, namely, closebreeding and linebreeding. Closebreeding is the mating of either a full or half brother to sister, of sire to his daughter, or dam to her son. These types of matings give the greatest concentration of similar "blood," and this concentration appears close up in pedigree. In fact, the concentration is discovered in the second generation back in all the cases listed as examples of closebreeding. Linebreeding is the mating of animals of wider degrees of relationship than those just stipulated for closebreeding, as, for example, the mating of cousins of various degrees or of a sire to his granddaughter, etc. Such a concentration will not be discovered until one works back to at least the third generation in the pedigree. In outline form this is as follows:

- Inbreeding
  - Closebreeding
    - Sire to daughter
    - Son to dam
    - Full or half brother to sister
  - Linebreeding
    - Matings of animals more distantly related than above, *e.g.*, cousin matings

Inbreeding in any degree reduces the number of different ancestors appearing in an animal's pedigree. That is, any animal must have two different parents, and could have four new and different grandparents, eight new and different great grandparents, sixteen new and different great, great grandparents, and so on

if no inbreeding had taken place. If any ancestor appears more than once in an animal's pedigree, inbreeding has taken place. It must be admitted that inbreeding has been extensively used in the formation of most of the breeds of livestock.

Bakewell's Work.—Robert Bakewell, an Englishman, born in 1725, was the man who first dared to use inbreeding in a constructive way. He worked with Longhorn cattle, Leicester sheep, and Shire horses. It is said that he secured two heifers and a bull after a great search for just what he wanted, and that his entire herd of cattle was developed from these without any outside blood. His success was remarkable and is today well known. Culley, writing in 1794, said:

> The great obstacle to the improvement of domestic animals seems to have arisen from a common and prevailing idea amongst breeders that no bull should be used in the same stock more than three years, and no tup more than two; because (say they) if used longer, the breed will be too near akin, and liable to disorders; some have imbibed the prejudice so far as to think it irreligious, and if they were by chance in possession of the best beast on the island would by no means put a male and female together that had the same sire, or were out of the same dam. Mr. Bakewell has not had a cross for upward of 20 years, his best stock has been bred by the nearest affinities, yet they have not decreased in size, neither are they less hardy, or more liable to disorder, but, on the contrary, have kept in a progressive state of improvement.

Since Bakewell's time his example has been emulated by many breeders. Breeds are best known by means of individuals and families, and most of the latter have arisen as the result of intensifying the characteristics of certain of the former through inbreeding.

Good Results from Inbreeding.—In practically any breed of livestock it is possible to find animals which have resulted from rather intensive inbreeding. As an example there is appended on page 186 the pedigree of Sybil's Gamboge, a famous Jersey bull.

It will be agreed that this is a rather closely inbred bull. The bull is a double grandson of Imp. Oxford Majesty, a triple great grandson of Royal Majesty, and a septuple great, great grandson of Gedney Farm Oxford Lad, as well as a triple great, great grandson of Oxford Ixia 3rd, a double great, great grandson of Lucy 12th, and a double great grandson of Fontaines Oxford Pride. Royal Majesty founded the Majesty family of Jerseys, which contains many notable show winners and producers. Sybil's

Gamboge sold for $65,000, one of his daughters sold for $10,000, another for $13,000, and a half sister for $18,000. Twenty of his get sold at auction in 1919 for an average of $3,245 and another twenty in 1920 for an average of $4,210. The "get" of Sybil's Gamboge won fourteen ribbons at the 1920 National Dairy Show, including one junior champion, three firsts, three seconds, two thirds, two fourths, two fifths, and one sixth, as well as second and fourth in the get of sire.

Sybil's Gamboge has 35 R. M. daughters of all ages with forty records averaging approximately 9,100 pounds of milk and 485 pounds of fat when converted to a 3 year old basis. The best record to be found among these daughters is one of

FIG. 59.—Sybil's Gamboge, a strongly inbred Jersey bull.

14,334 pounds of milk and 840.44 pounds of fat made by Sybil's Bay Girl as a junior four-year-old cow. Sybil's Gamboge also has six proved sons.

Gentry's Results.—N. H. Gentry, a successful breeder of Berkshire swine, is quoted by Mumford as saying:

> If it is true that inbreeding intensifies weakness of constitution, lack of vigor, or too great fineness of bone, as we all believe, is it not as reasonable and as certain that you can intensify strength of constitution, heavy bones, or vigor, if you have these traits well developed in the blood of the animals you are inbreeding? I think I have continued to improve my herd, being now able to produce a larger percentage of really superior animals then at any time in the past.

The above examples illustrate the fact that not only during the foundation period of the breeds was inbreeding a potent factor for improvement but that it still retains its potency.

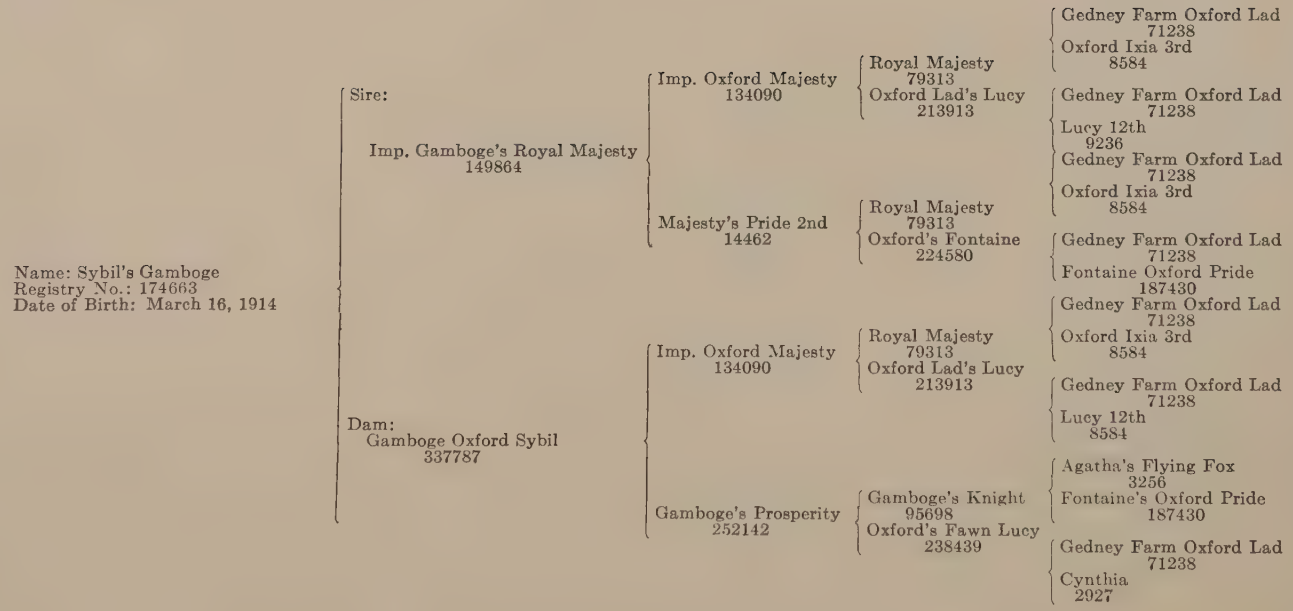


FIG. 60.—Pedigree of Sybil's Gamboge.

Harm from Inbreeding.—In exactly similar manner, one might unearth opinions and examples both in the past and in the present which would indicate that inbreeding is an extremely dangerous practice and that anyone using it is apt to encounter serious difficulties. This will not be done, however, since one may take half the figures or data and support any point. There are many references in the literature of animal husbandry as to the harmful results from the practice of inbreeding.

Experimental Data.—Much experimental work has been done with a view to illuminating the problem of inbreeding. Castle says in regard to some inbreeding experiments with Drosophila:

> My pupils and I bred brother and sister for fifty-nine generations in succession without obtaining a diminution in either the vigor or the fecundity of the race, which could with certainty be attributed to that cause. A slight diminution was observed in some cases, but this was wholly obviated when parents were chosen from the more vigorous broods in each generation. Nevertheless, the crossing of two inbred strains of Drosophila, both of which were doing well under inbreeding, produced offspring superior in productiveness to either inbred strain. Even in this case, therefore, though inbreeding is tolerated, crossbreeding has advantages.[1]

Bos and Weismann inbred rats for about thirty generations and secured a diminution in both fertility and vigor (see Chap. V). King also inbred rats for twenty-five generations and, according to Hays, found that

> Inbred males in seventh to fifteenth generations were 18 per cent heavier than check males not inbred. Inbred females were about 3.7 per cent heavier than controls at one year old. The variability in body weight at maturity of the fifteenth generation of inbred males and females was about 40 per cent less than among the control animals. King (1918) also studied the effect of inbreeding on fertility, the time of puberty, and the longevity of albino rats inbred brother and sister mating for twenty-five generations. The average size of litter of all inbred matings was 7.5 rats; and the average litter size for controls 6.7 rats. Inbred rats seemed to reach sexual maturity and to breed slightly earlier than stock females not inbred . . . The number of sterile animals is not given, but King states that inbreeding did not decrease the productiveness of the animals. Inbred rats lived longer than control animals not inbred. The value of selection in inbreeding animals is

[1] Castle, W. E., "Genetics and eugenics," p. 221, Harvard University Press, 1916.

concisely illustrated in this painstaking and thorough study of the question of inbreeding.[1]

Reporting on his extensive investigations, Wright says:

There has been an average decline in vigor in all characteristics during the course of 13 years of inbreeding of guinea pigs, brother with sister. The decline is most marked in the frequency and size of litter, in which it is so great that it would have to be accounted for even though the decline in other respects were assumed to be due wholly to a deterioration in the environmental conditions. The decline is greater in the gains after birth than in the birth weight, and greater in the percentage raised of the young born alive than in the percentage born alive. The ability to raise larger litters has fallen off much more than ability to raise small litters.

A comparison of the inbred guinea pigs with a control stock, raised under identical conditions without inbreeding, and derived in the main from the same linebred stock as the inbred families, indicates that the inbreds have suffered a genetic decline in vigor in all characteristics. The decline in fertility is again shown to be most marked. Experimental inoculation with tuberculosis has shown that the inbreds were inferior, on the average, to the controls in disease resistance. A study of sex ratio yields results in marked contrast to those obtained in connection with the other characters. There are no significant fluctuations from year to year, no contrast between inbreds and controls, and no indications of change due to inbreeding.

In addition to the points brought out in this bulletin, which indicates genetic decline during inbreeding, extensive experiments have been made in which different inbred families have been crossed together. These are described in another paper (*U. S. Dep't Agr. Bull.* 1121), in which it is shown that crossbred guinea pigs born of unrelated inbred parents are distinctly superior to their inbred relatives in nearly all elements of vigor. A slightly larger percentage are born alive, in small litters at least, and a distinctly larger percentage of those born alive are raised. The young are slightly heavier at birth in a given size of litter and gain much more between birth and weaning. They mature earlier, produce larger litters, and produce them more regularly than inbreds. Of the young which they produce, a much larger percentage are born alive, especially in large litters, and even more of these are raised than in the first generation. Their young show a further increase in birth weight and in later gains.

Combining the results described in this and in *Bull.* 1121 there seems no escape from the conclusion that a loss of vigor, especially in fertility,

[1] Hays, F. A., Inbreeding animals, *Del. Agr. Exp. Sta. Bull.* 123, p. 15, 1919.

took place as a more or less direct consequence of close inbreeding. The question whether this is an inevitable result of inbreeding, or merely a likely one, as well as other phases of the subject, will be discussed after the presentation of further data.[1]

Rôle of Inbreeding.—Scientists at the present are quite well agreed that what inbreeding actually does is to fix characters. These characters may be either good, bad, or indifferent and, whatever they are, inbreeding will not change them in the least. Inbreeding is no more potent than any other system in creating new characters of any sort. All that inbreeding does is to take the characters that are present and sort them out into a homozygous form. For instance, if an animal was carrying several factors or determiners for characters in the heterozygous form, that is, one parent after reduction had put in *AbC* and the other one *aBc*, the hybrid would carry *Aa Bb Cc*. If such an animal were bred to another animal of very similar breeding (therefore similar genetic constitution), the factors would tend to combine in all possible combinations from *AA BB CC* to *aa bb cc*. Then if sufficient numbers were available, so that rigid selection could be practiced, the *AA BB CC* type could be selected out. Supposing that, in the above, the capital letters stood for desirable characteristics and the small letters for undesirable ones, one can see why inbreeding may give either good or bad results. For *AA BB CC* animals with no recessive, undesirable factors would be a decided improvement over either parent, while *aa bb cc* animals would be just the reverse. It will bear repeating that inbreeding is powerless to create either good or bad. It is, however, the very best method of finding out what is present in a strain, for inbreeding will sort out the various characteristics into a homozygous condition. The desirable animals may then be retained and the undesirable ones discarded.

Necessity of Rigid Selection.—Along with inbreeding must go rigid selection. Selection is the foundation upon which any system of breeding is built, and the more intricate and refined the system (inbreeding is the most intricate and refined) the more rigid must be the selection. Animals showing any weaknesses should never be retained in any inbred herd or flock, or disaster is quite likely to result.

[1] WRIGHT, S., The effects of inbreeding and crossbreeding on guinea pigs, *U. S. Dept. Agr. Bull.* 1090, pp. 31–32, 1922.

Use of Inbreeding.—Plant breeders are putting their knowledge of inbreeding to very good use. Their system consists of self-fertilizing corn for several generations and selecting out the best offspring. These come out eventually in a very pure state, *i.e.*, homozygous. They may, usually do, lose in size and vigor, but they gain in uniformity, the ears in each inbred strain being almost exactly similar in size and shape. Four of these inbred strains are secured and then two hybrid strains are produced by crossing in each case two inbred strains. These hybrids are extremely vigorous and grow larger and yield much better than either parent. These two derived hybrids are then crossed. This gives a second kind of hybrid which greatly exceeds the original parent stock in size, yield, and vigor. Keeping the four inbred strains in a pure state is perhaps too complicated for the average farmer, but seedsmen can utilize such a system to good advantage.

Hathaway[1] has pointed out the parallel in animal breeding:

> Close breeding or inbreeding made for uniformity. It brought to the surface faults which were hidden and yet which were always present and ready to crop out at some future time. Selection had to go hand in hand with the inbreeding to preserve that which was good and to discard that which was evil.
>
> To illustrate the principle of crossing two lines purified by inbreeding or line breeding—all who saw the junior champions (Durocs) at the National Swine Show this year (1920) are willing to concede that they were individuals of a superior order.

The following figure shows the pedigree of Fannie's Top Colonel, 182693, the Junior Champion Duroc boar at the National Swine Show in 1920.

Walt's Top Colonel is thus seen to be a linebred Colonel boar, and Orion Fannie II a closebred Cherry King sow. The crossing of these two rigidly selected inbred strains produced animals of championship caliber.

Coefficient of Inbreeding.—Dr. Raymond Pearl devised the following system for the numerical expression of the degree of inbreeding and the degree of relationship between the sire's and the dam's sides of the pedigree. While this numerical expression simplifies and clarifies matters very greatly, it should be emphatically stated that no system has yet been nor ever will be devised

[1] HATHAWAY, F. S., A study of breeding, *Duroc Bull.*, **17** (7), 102–104, 1921.

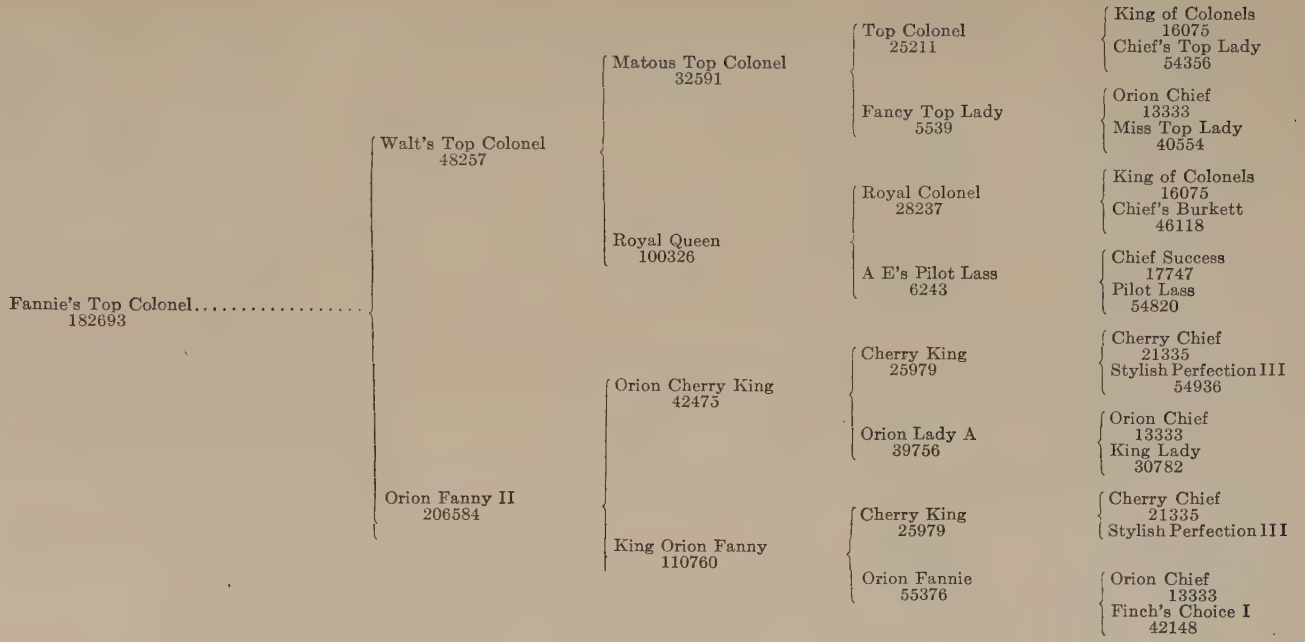
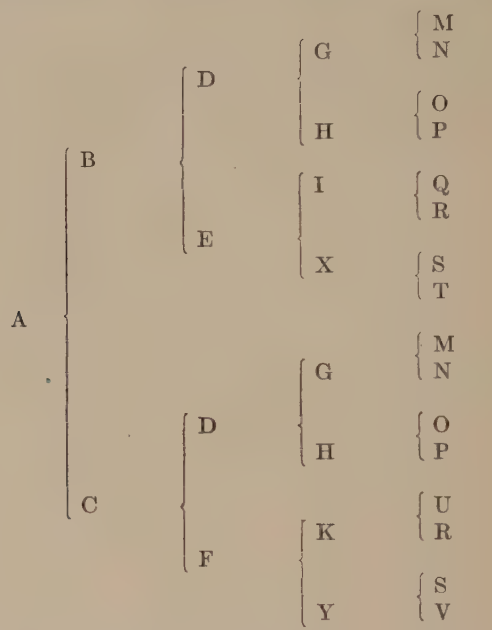


FIG. 61.—Pedigree of Fannie's Top Colonel, 182693.

that will do away with the need of studying the actual pedigree and of knowing intimately the animals contained in the pedigree. The following is not intended as a short cut in evaluating pedigrees, but merely as an aid in revealing at a glance whether an animal is closebred or linebred and the degree of relationship between the sire's and the dam's sides of the pedigree. The following schematic pedigree is analyzed according to Pearl's method.



Per cent inbreeding	$Z_o = 0$	$Z_1 = 25$	$Z_2 = 25$	$Z_3 = 37.5$
Per cent relationship	$K_o = 0$	$K_1 = 50$	$K_2 = 50$	$K_3 = 75$
Per cent inbreeding due to relationship	$KZ_o = 0$	$KZ_1 = 100$	$KZ_2 = 100$	$KZ_3 = 100$

FIG. 62.—Pedigree with coefficients of inbreeding and relationships.

It will be seen at a glance that there has been considerable inbreeding in the schematic pedigree given above. In the first place, bull B and cow C are half brother and sister, having the same sire D, but they are more than this because their dams E and F are double first cousins. Even such a comparatively simple relationship is hard to grasp and visualize and the more complex ones are a hopeless tangle of "his sisters and his cousins and his aunts."

Pearl uses Z as the coefficient of inbreeding and this is derived as follows: In the first generation Z_o the value is bound to be o because one animal must be a male and the other a female, therefore they could not be the same animal. In the next, grandparental, generation Z_1, there could possibly be four new and different individuals. However, there are but three new and different ones, bull D appearing twice; therefore, we have $\frac{(4-3)\times 100}{4} = 25$ in other words, $Z_1 = 25$. The coefficient 25 for Z means that in the grandparental generation there are 25 per cent less new and different individuals than there might have been—in other words, there has been closebreeding to this extent. Inbreeding results in a reduction in the number of an animal's new and different ancestors. In this second generation they are reduced by 25 per cent. Likewise, for the next generation, it would be possible to have eight new and different great grandparents; however, one finds on examination that there are but six new and different ones. Therefore, $Z_2 = \frac{(8-6)100}{8} = 25$ per cent, that is, in this generation only the parents of animal D are repeated and there are no new "repeats." For the great, great grandparental generation Z_3, there might possibly be sixteen new and different animals, but, on counting, there are found to be only ten. Therefore, $Z_3 = \frac{(16-10)100}{16} = 37.5$, which means that in this fourth generation back there are 37.5 per cent less new and different individuals than there might have been. In other words, there has been inbreeding to this extent.

Coefficient of Relationship.—Now it would be possible to use a strongly inbred Holstein sire on a strongly inbred Guernsey cow and, by the above formula, to derive a high degree of inbreeding for the resulting offspring. This would be very misleading. To obviate this difficulty, Pearl has devised another formula whereby one may state the amount of the inbreeding that is due to relationship between the sire and the dam. This relationship is designated by the letter K. Again referring to the pedigree listed above, the values for K are derived in the following manner. Inasmuch as the animals in K_o, or the parental generation, are a female and a male, there is no possibility of their being the same animal; therefore, the value for K_o, like the value for Z_o, will always be o. In the next K_1 or grandparental generation, con-

sidering the top half of the pedigree in relation to the bottom half and *vice versa*, there could possibly be two new and different animals, that is, animals that have not already occurred in the present or any previous generation in the other half of the pedigree. It is found, however, that there is one animal D in the lower half that has already occurred in the upper half. In other words, there is one "repeat;" therefore, the value for $K_1 = \frac{1(100)}{2} = 50$. As there are no new "repeats" in K_2, the value for K_2 is the same as for K_1, namely, 50. Finally, considering the next or great, great grandparental generation, one finds six animals, M, N, O, P, R, and S, that have already occurred in the top half of the pedigree; therefore, $K_3 = \frac{6(100)}{8} = 75$. Expressed in words, these coefficients mean that bull B and cow C are related to the amount or degree of 50 per cent in their first generation back, 50 per cent in their second generation back, and 75 per cent in their third generation back. To go back to the first assumption of breeding an inbred Holstein on an inbred Guernsey, it will be seen that though one might get a high value for Z, the coefficient of inbreeding, one would always get a zero value for K, because there would be no animals occurring in both the top and bottom side of such a pedigree.

Percentage of Inbreeding Due to Relationship.—Finally, the amount of the total inbreeding observed in any generation that is due to the relationship between the sire B and dam C may be expressed according to the formula:

$$KZ = \frac{50(\text{value of } K)}{\text{value of } Z} \text{ for any generation.}$$

For the above pedigree

$$KZ_o = o$$

$$KZ_1 = \frac{50(50)}{25} = 100$$

$$KZ_2 = \frac{50(50)}{25} = 100.$$

$$KZ_3 = \frac{50(75)}{37.5} = 100.$$

In other words, all of the inbreeding observed in this schematic pedigree is due to the relationship between the sire and dam, though, of course, it need not necessarily all be due to such relationship. In like manner, the exact degree of relationship K

for any two animals might be considered altogether independent of any consideration of inbreeding.

The above system requires the application of a little common sense and arithmetic in consequence of which one may secure a definite numerical expression of the exact percentage of inbreeding that occurs in a given animal's pedigree and the percentage of this inbreeding that is due to relationship between the sire and the dam of the animal in question, and if desired the percentage of the total inbreeding observed in any generation that is due to relationship between the sire's and the dam's side of the pedigree. The Z and K values are a symbolic language which expresses in brief terms a mass of interrelationships that would otherwise be entirely too complex to be grasped and retained in the mind. It should also be borne in mind that individual Z and K values are of no value without the pedigree itself, because they do not reveal the system of breeding in use. For instance, the matings of half brother and sister and parent and offspring give identical Z_1 values. In addition, it should be recalled that a pedigree is a record of ancestry which is invaluable if the individuals occurring in the pedigree are known either through direct contact or study, but almost worthless if the individuals are not known. If one knows the individuals and the way the blood lines have been blended, the Z and K values are perhaps superfluous. However, the Z and K values are indispensable in evaluating a group of animals, as, for instance, all the animals in a herd, the class leaders in a breed, etc.

Relationship Coefficients.—The following are the values of the relationship coefficients, or K, for various degrees of kinship.

TABLE XVI.—TABLE OF RELATIONSHIP COEFFICIENTS
(*After Pearl*)

Degree of kinship	K_1	K_2	K_3	K_4
Brother and brother (or sister)	100	100	100	100
Parent and offspring	50	50	50	50
Half brother and half brother (or sister)	50	50	50	50
Double first cousins	0	100	100	100
Single first cousins	0	50	50	50
Uncle and nephew (or niece)	0	50	50	50
Grandparent and offspring	0	25	25	25
Quadruple second cousins	0	0	100	100
Double second cousins	0	0	50	50
Single second cousins	0	0	25	25

The relationship between a full brother and sister in the K_1 or second generation back is seen to be 100 per cent, that is, these animals have the same sire and the same dam; between a half brother and a half sister in the K_1 or the second generation back the value is 50, that is, they have either the same sire or the same dam; for a grandparent and offspring in K_2 or the third generation back the value is 25, that is, in this generation one animal of the four has already occurred in the other side of the pedigree. This system yields a very definite numerical value which can be comprehended much more easily than descriptive terminology.

Examples of Inbreeding.—Constructive breeders have always used more or less inbreeding in order to intensify the desirable characteristics present in their stock and to increase its unformity, and no doubt they will continue so to use inbreeding. The writer has examined the sale catalog of the animals sold at the Langwater dispersal sale in May, 1922. Mr. Ames was a constructive breeder, one of the greatest the Guernsey breed has ever known, and he utilized inbreeding to a considerable extent. The average price that these ninety-six animals brought at auction was $2,770. Below is a table showing the amount of inbreeding in four generations back of a few of the animals which sold at prices ranging from $450 to $25,000.

TABLE XVII.—*Z* VALUES FOR SOME ANIMALS IN LANGWATER SALE

Name	Z_1	Z_2	Z_3	Price brought
Langwater Warrior	0	0	37.5	$15,000
Langwater Steadfast	0	25	50	25,000
Langwater Horatius	25	25	25	16,000
Langwater Cleopatra	0	0	12.5	19,500
Imp. Gay Mike's Chemmante	25	25	25	1,700
Langwater Valiant	25	25	25	Reference
Langwater Elegy	0	12.5	31.25	3,200
Langwater Memoir	0	0	0	13,000
Rose of Langwater 2nd	0	37.5	37.5	6,000
Langwater High Caste	0	37.5	37.5	5,000
Langwater Gardenia	0	12.5	31.25	8,000
Langwater Golden Rose	0	0	0	4,500
Langwater Yvette	0	25	37.5	2,500
Imp. Hay's Lady May II	0	0	0	1,000
Langwater Radiant	25	37.5	50	5,000
Langwater Clara	0	0	0	450

For the sake of comparison, the following table showing Z values for various degrees of relationship is given and also these values for some famous animals in various breeds.

TABLE XVIII.—TABLE OF Z VALUES

	Z_1	Z_2	Z_3
Full brother and sister (continued)	50	75	87.5
Parent and offspring (continued)	25	37.5	43.75
Half brother and sister (continued)	25	37.5	43.75
Double first cousins	0	50	50
Single first cousins	0	25	25
Comet (Shorthorn)	50	62.50	
Sovereign (Hereford)	25	37.5	62.5
Mischief Maker (Hereford)	0	25	50
Anxiety 4th (Hereford)	25	37.5	
Countess Prue (Guernsey)	0	0	0
Lad's Iota (Jersey)	0	0	0
Sybil's Gamboge (Jersey)	25	37.5	62.5
Dutchess Skylark Ormsby (Holstein)	0	0	
Tilly Alcartra (Holstein)	0	12.5	12.5
Lilly of Willomoor (Ayrshire)	0	0	

Conclusion on Inbreeding.—From the above table, as well as from a consideration of the whole problem of inbreeding, one is forced to conclude that inbreeding in itself is powerless to create either good or bad. If good or bad is present in the germplasm, inbreeding will sort it out and bring it to light. Closebreeding may be used if accompanied by very rigid selection. For the average man, linebreeding, a less intense form of inbreeding, is decidedly safer. This consists of mating animals of the same general line of descent. Because they are of the same line, they have the same general type of germplasm, and so exhibit the same general set of characteristics. In other words, a linebred herd or flock is extremely uniform, a characteristic almost invaluable (if of a good sort) in animal breeding. In a general way, closebreeding has the greatest possibilities both for good and for harm, linebreeding has next to the greatest possibilities both for good and for harm, while outbreeding or mating of animals of no degree of kinship has the least possibilities for good and the least danger of producing harmful results. If the breeder be keen enough in mating his animals and severe enough in culling, he may practice closebreeding. Such pioneering requires both

courage and skill. For the conservative standpatter, outcrossing is the system to be advised. The majority of breeders ought perhaps to seek the middle road, the happy medium. Their desire is to progress, but they cannot afford to take great chances.

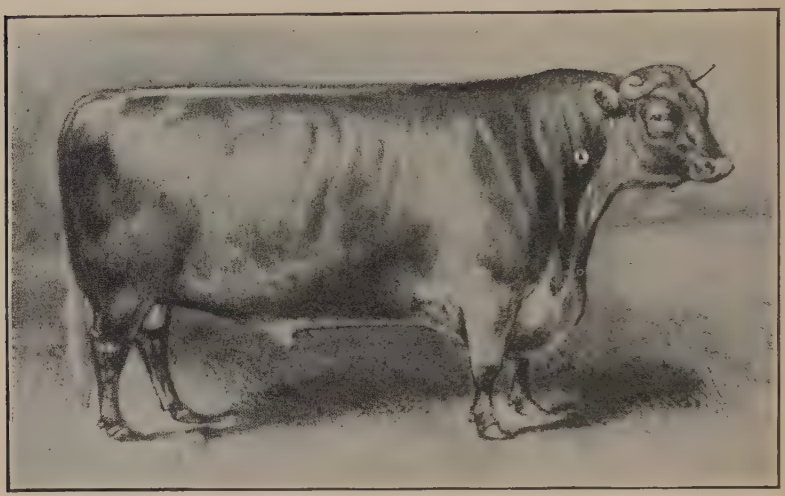


FIG. 63.—Comet (155). The first bull ever sold for $5,000. He was very strongly inbred. (*Photo. from Sanders, Shorthorn Cattle, The Breeders Gazette.*)

For such breeders both their hope and their safety lies in line-breeding. *The success or failure of any system of breeding lies first in the characters* (*strong and weak*) *which the animals exhibit*

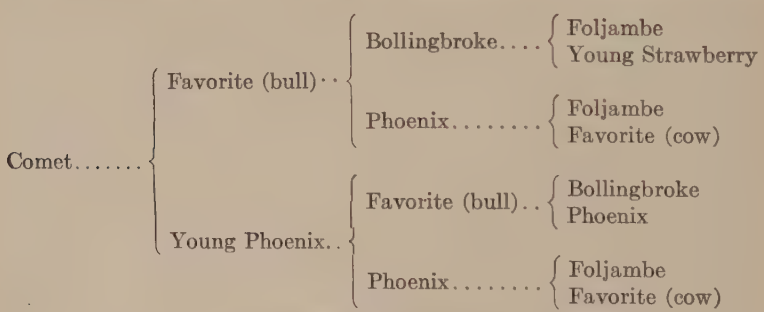


FIG. 64.—Pedigree of the Shorthorn bull Comet.

and second in the breeder's ability to balance defects and mate wisely—in other words, his ability to *select.*

Purebreds have existed for many decades. They have, of necessity, been bred more or less closely, so that inbreeding is

perhaps not so necessary now as it was in founding the various breeds. It is necessary, however, for any constructive breeder to find the best and most prepotent blood in his breed, to secure a worthy sire carrying that blood, and then to intensify this blood through some form of inbreeding. Many of the greatest breeders, past and present, have accomplished this result by having their new sires sired by the old tried herd sire and out of a female of exceptional merit, but of somewhat different blood lines. Such an animal when bred to the females in the herd intensifies the old sire's blood.

CHAPTER XVI

SELECTION

Selection is the key to all the progress that man has made in the breeding of better livestock. A study of animal breeding can only be justified in the hope that it will yield a more efficient selective index so that more nearly ideal forms may be created. All types of inquiry in the field of animal breeding converge in selection. According to Darwin, "natural selection" is responsible for the survival of all the existing organisms on earth. Nature selected them (a passive rather than an active selection, it should be noted) because they were the best fitted to survive under the given conditions. The most efficient are the only

FIG. 65.—Double's Duchess 5th a Hood Farm bred Berkshire sow. Her conformation won her a grand championship at the International and is of the kind generally conducive to fertility. Long bodied hogs are best from the packers standpoint also as they yield a greater amount of the valuable cuts.

survivors in the wild state. The same result should be true under domestication. The recently inaugurated herd test plan of the Ayrshire breed is especially to be commended because men will be moved quickly to dispose of low yielders, since all cows in the herd must be tested, as every cow has an influence on the average production figure for each herd.

Scope of the Problem of Selection.—In the selection of the animals to produce the next generation, there are so many things

to be considered, so many angles from which the problem should be viewed, that on first thought it seems almost too much to expect ever to work out an orderly plan in which all phases of the problem will receive the attention each merits. There is the matter of the market, the type, the breed, the breeder's ideal, the individual, the pedigree, the performance test, the cost, the fertility, the types of variations, the system of breeding, the likelihood of "nicking" favorably, and many other things, each important enough to merit all the thought that can be given to it. In general, a breeder's problem is twofold—first, the production of something for which the market will pay a fair price, and, second, having each succeeding generation better than the preceding one.

FIG. 66.—Different types of Berkshire boars. Left, Willow Lodge Baron 8th Grand Champion International 1923; right, Pearls Successor 8th Grand Champion Eastern States 1920.

Market Demand.—The first consideration must necessarily be market demand—not because the market demand is always just or sensible, but because most breeders must make their living through selling the animals they breed. The mere fact that they have produced efficient and attractive animals will not of itself prove profitable if the market does not happen to be in the mood to buy that particular sort of animal. The breeder who is to get ahead must be a keen student of what the market demands and is apt to demand in the next few years. This should not, in the slightest degree, be construed to mean that breeders should follow every whim of the market and be continually changing type. Such practice can lead to nothing but chaos. The successful breeder is the one who can sense the difference between a passing whim and a permanent change. The market is not a fixed institution incapable of change. For substantiation of this, one need but refer to pictures of accepted

animal types of twenty years ago and to consult market statistics of two decades past. The progressive breeder senses each change somewhere near its beginning and shapes his course accordingly. Before turning his hand to produce anything, every breeder and farmer should reflect on this most important of all questions, What will the market pay me best to produce? Until that question has been answered, there can be no consistent selection.

Breed.—After the general type of animal which will best fill the market demand has been determined comes the question of breed. A stock phrase for many years has been, "There is no best breed," though this statement is only true when there has been added "for all conditions." There are breeds better suited to certain conditions than are others of the same class, because certain breeds have been grown under and with a view to fulfilling similar conditions to the ones now contemplated. Breed tests of various sorts are likely to be very misleading, because in them it is more apt to be the particular strain rather than the breed as a whole that is being tested. If enough so-called breed tests were run, no doubt all of the breeds would get their share of the winnings. A breeder will find it profitable to make a study of the breeds in order to ascertain which one has been produced under conditions similar to his own and has given the most general satisfaction therein. On the other hand, caution must be exercised in accepting the offerings of over-enthusiastic breed advocates. This matter of an unbiased opinion and a thorough knowledge of the breed from its earliest inception to the last sale and show-yard winning or loss cannot be overstressed. Such knowledge is essential before a pedigree in the breed can be properly evaluated. It is incumbent upon a breeder to acknowledge that his particular breed has faults and to work toward the improvement of his stock.

Individuality.—The three major aspects of the problem of selection are those relating to the individual, the pedigree, and the progeny performance test. All these considerations are important, though there can be no question but that the progeny performance test takes first rank. A good individual and a good pedigree are obviously considerations of great importance. A deficiency in either individual or pedigree is a danger to be sedulously avoided. Selection based on individuality alone or on pedigree alone, however, will only involve temporary loss and setback, provided the progeny performance test is rigorously applied.

A thorough study of its physical make-up is essential in selecting an individual to go into the breeding herd. It is here that knowledge of anatomy and practice in judging livestock will stand the breeder in good stead. There can be no question but that livestock shows are the most influential factors in establishing type, and breeders generally would profit by more regular attendance at the leading livestock shows. Like other arts, livestock judging is more or less a gift, but it, too, can be improved through study and practice. The animals that go to make up a herd should be as nearly perfect as possible, but in all animals it is

FIG. 67.—Kings Gazelle Fawn one of the Jerseys in the St. Louis Exposition breed test 1904.

possible to find faults of various sorts. This being true, wise selection will depend on the breeder's ability to balance one fault or several faults against others and to choose the least of the evils. Here the breeder's ideal must hold the center of the stage, and other things, for the time being at least, be subordinated to it.

In selecting foundation animals, it is essential that there be as much uniformity as is possible in the band of females. If these are of different types it will be extremely difficult to get a sire which, when mated with them, will be able to produce a uniform type of offspring. In visiting herds or sales for the purpose of securing foundation animals one of the cardinal features to be observed and appraised is this matter of uniformity. Uniformity of a

good sort is a virtue almost beyond price. One should hesitate, if not entirely refrain, from buying animals out of a flock or herd that evidences samples of all conceivable types. The females, besides being uniform in type, should be of good size in order to facilitate prolificacy and to promote efficiency. The desideratum is as much size as is consistent with quality. Size, however, as well as anything else can be overdone. If the females of any class of livestock are not fairly roomy and stretchy through the middle, the most important feature of all in breeding livestock, namely, fecundity, is apt to be low. In selecting the sire to

FIG. 68.—Merry Maidens 3rd Son. One of the two Jersey bulls at the head of the demonstration herd at the St. Louis Exposition 1904.

mate with a uniform band of good-sized females, the cardinal point to be borne in mind is that he should offset any faults that are present in the females. If the females have a tendency to sloping rumps, the male should be particularly strong and level in this respect; if they show weak pasterns, he must stand well up on his toes, and so on. If size and vigor are present in the females, one can logically accept a little more compactness and quality in the male, especially if producing meat animals. An exception ought perhaps also to be made in the case of draft horses, where size and weight are the outstanding requirements. In the sire, there should be evidence of masculinity, but it should be remem-

bered that this is often overdone at the expense of quality. Breed history, both good and bad, must also be considered. Particularly is it essential in selecting animals of any breed to avoid those individuals exhibiting the common breed faults, such as droopy rumps in Holsteins, small teats in Ayrshires, too fine bone in Percherons, undue coarseness in Chester Whites, and so on through all our breeds of livestock.

Pedigree.—After the individuality of the animal has received due consideration, it becomes necessary to consider carefully the pedigree. A good individual which has back of it a poor pedigree should be tested thoroughly before being allowed to perform heavy breeding service. It is possible, of course, that this favorable "nick" will prove to be prepotent, equally possible that it will not. The only way to ascertain any animal's powers is to test each thoroughly.

Unless the breeder can call up a mental picture of most of the animals represented in a pedigree for three or four generations back and unless he knows intimately, through contact or study, the good and bad features embodied in these individuals, he is in no position to pass a reasonable, sensible judgment on the animal in question. Selection based primarily upon pedigree has in the past ruined many breeders. Nevertheless, the best indicator of the type of offspring any animal is likely to produce is the type of ancestors found in the first three or four generations of its pedigree.

Attempts have been made to work out a mathematical formula for evaluating the animals in a given pedigree, but the problem will never resolve itself into so simple an interpretation. One of the most common mistakes is that of assigning great value to a pedigree in which some famous animal occurs in a remote generation. Nothing could be more misleading. Another erroneous practice is to say that each of the immediate parents contribute 25 per cent of the individual's "blood," each grandparent 12.5 per cent, and so on back. They may contribute this much or more or less, depending on individual prepotency, system of breeding used, and so on. The only safe method is to know personally in one way or another the animals involved in a pedigree, bearing in mind that, in a general way, the animals close up exert most influence and that this is likely to decrease rapidly as one goes back to the more remote ancestors. A remarkably good or a remarkably poor individual six generations back in most cases

means nothing in itself, and by the same token a remarkably good or a remarkably poor individual in the first or second generation back is of great moment. The poor individuals close up should be properly appraised as well as the good ones. The pedigree, as a whole, should carry a moderately high degree of excellence all the way back rather than be made up of a mixture of very good and very poor or unknown animals.

FIG. 69.—Sociable Sybil 17 times a Grand Champion Jersey cow including the National Dairy show 1923.

Pedigree Values through Correlation Studies.—Gowen has studied the A. R. S. O. records in the Holstein-Friesia breed in order to find answers to the following questions: (1) Is the milk yield of a cow determined by her sire either in whole or in part? (2) Is the milk yield of a cow determined by her dam either in whole or in part? (3) Do the grandparents or ancestors further removed have any marked influence on the milk yield of their granddaughters? He secured the following correlation coefficients: Coefficients of milk yields of full sisters 0.55; half sisters with the sire as the common parent 0.37; half sisters where the dam is the common parent 0.38; from which he concludes that the joint influence of sire and dam makes for greater resemblances between two sisters than for either of the half sisters and

that the influence of the sire or dam on milk yield of half sisters is approximately equal. The correlation coefficients between granddaughter's milk yields for the paternal grandsire was found to be 0.07 and for the maternal grandsire 0.24, indicating that the grandsires influenced the milk yield of their granddaughters to about one-half the extent of the parental influence. The correlation coefficient between milk yields of daughters and dam was

FIG. 70.—Ferns Wexford Noble, Grand Champion Jersey Bull at National Dairy Show 1922, 1923 and 1924. A son was grand champion 1925 and another son was junior champion.

0.50, between granddaughter and paternal granddam 0.26, between granddaughter and maternal granddam 0.31, indicating that the influence of each granddam is about equal and each about one-half that of the dam. This shows the influence of the grandparents to be about one-half that of the parents and Gowen found that great grandparents show little direct influence on the milk yield of their great granddaughters.

Similar relationships to those given for the milk yield exist for the butterfat percentage. The correlation coefficient for the butterfat percentages of full sisters is 0.52; that for half sisters where the sire is the common parent is 0.38; that for the half sisters where the dam is the common parent is 0.12. The correlation coefficients for the grand-

daughters of the paternal and maternal grandsires are 0.18 and 0.22, respectively. The direct relationship of the butterfat percentages of daughter and dam is 0.41. The correlation coefficients for the granddaughters' butterfat percentages with the paternal and maternal granddams' butterfat percentages are 0.09 and 0.19, respectively. These constants make it clear that the same general relationships exist for the inheritance of butterfat percentage as exist for milk yield. In other words, the bull and the cow are jointly and equally responsible for the milk yields and butterfat percentages of their daughters. The grandparents influence the milk yields and butterfat percentage of their granddaughters to only about one-half the extent that the parents affect these variables.

A basis is now established for a consideration of certain practices in use in animal breeding. It is obvious that only those ancestors in the first and second generations are of any pronounced influence on the milk yields of their progeny. Such being the case, it is equally clear that much of our pedigree study as it has been carried on in the past is faulty, since the greatest emphasis is laid on those animals occurring in the third and fourth generations of the pedigree. Instead of trusting to famous ancestors in the third or fourth generation, let us insist rather that the parents have high milk records.[1]

In planning matings, pedigrees should be studied in order that bloodlines may be blended properly. Hard-and-fast rules cannot be laid down. It is a matter of reflection and judgment requiring intimate knowledge of the dominant characteristics of the strains in question. Some strains are too fine, others too coarse, some mature quickly, others slowly, butterfat percentage is high in some, low in others. To mate wisely, so that in all probability there will be blended in the offspring some of the extremes found in the parents is an art in the achieving of which pedigree study has its legitimate function.

Unjustified merit is sometimes assigned to any and all animals of certain strains or families. In common vernacular this is known as a "pedigree craze." They are sometimes propagated for the sake of restricting competition and the livestock breeder will do well to investigate thoroughly before shaping his course by them. Utility rather than popularity will, in the final analysis, be the criterion by which all classes, breeds, strains, and individuals will be tried. This should not be construed in any way to mean that certain strains or families are not better pro-

[1] Gowen, J. W., The inheritance of milk yield, etc., *Proc. Amer. Soc. An. Prod.*, p. 103, 1922.

ducers of speed, milk, flesh, wool, or what not than are others because such a construction would be entirely removed from the truth.

Mass versus Progeny Performance Selection.—There are two possible interpretations of improved performance: (1) that selection in itself modifies the germinal elements and that by selecting in a specific direction the hereditary material itself is actually molded in a corresponding fashion, and (2) that the effectiveness of selection depends upon the isolation of hereditary material of the most excellent sort. It will be seen that the two views are diametrically opposed to each other and it is necessary to make a choice of one or the other interpretation and upon that choice will depend the method of selection adopted. If the first explanation is accepted it will involve only mass selection of those individuals that are themselves better than average producers. If "performance brings about the development of more favorable hereditary material, or if selection in itself has a creative effect in a given direction, then it would seem that mass selection must result in increased production."

Mass selection was practiced with poultry at the Maine Agricultural Experiment Station beginning in the year 1899. From this time until 1907 only those females were used as breeders that produced at least 160 eggs in their first year, only males whose mothers laid at least 200 eggs in their first year. Under this system of selection the yearly egg production decreased steadily. The point to be noted here is that mass selection failed to increase production in the hereditary material involved.

After 1907, the system of selection was changed. All females were now selected from high-producing mothers the female progeny of which were all high producers and in case such a female failed to yield high-producing progeny the first year she was not retained in the breeding flock. Males were selected from high-producing mothers whose female progeny were all high producers and a male was discarded immediately if his progeny failed to be high producers. Pedigrees were also kept and proper attention given to the blending of blood lines. With such a system in vogue, the production increased steadily from 1908 to 1920.

Here is critical evidence to substantiate the impotency of mass selection alone and the efficacy of individual selection plus progeny performance test and proper blending of blood lines. In

any breed of livestock, it is possible to show that improvement has come not through the gradual raising of production by the mass, but through the blending either by chance or under man's guidance of a favorable type of germplasm in one or a few individuals which have, in turn, passed this favorable germplasm on to their offspring. In Standardbred horses, the influence of Hambletonian 10 is as great as it is well known. This animal, though not particularly fast himself, carried and passed to his offspring germplasm with maximum possibilities for the development of speed. As Davenport has shown, the ten greatest producers of speed in the Standardbred horse are all sons, grandsons, or great grandsons of Hambletonian 10. In Herefords, almost as great an influence has been wielded by Anxiety 4th, a strongly inbred bull.

Progeny Performance in Dairy Cattle.—Among the dairy breeds of cattle, data which substantiate the isolation interpretation rather than the creative effect of selection are accumulating rapidly through the advanced registry. Prof. J. M. Hover in studying Guernseys in 1916 found that

> . . . 278 sires produced 332 equivalent of 600-pound daughters, or 1.9 each, 35 sires produced 178 equivalent of 600-pound daughters, or 5.08 each. The 35, in other words, were more than four times as prepotent for butterfat as the remainder of the 278 sires of 600-pound cows. The 35 sires are only 0.092 per cent of the male animals registered in the A. G. H. B. and 2.13 per cent of the 1,642 sires of advanced registry cows. The tremendous importance of the few strong sires from the standpoint of improving the production of the breed becomes quite apparent. Indeed, it can be safely assumed from the above facts that less than one out of every thousand of the registered male animals will have a marked tendency to raise the production of the breed above the 600 pound level.

In studying the pedigrees of these thirty-five prepotent sires, it was found that nearly all of them could be grouped into a few families, principally the "May Rose," the "Masher," the "Governor of the Chene," the "Glenwood," and the "Sheet Anchor." A later study of Guernsey sires made by the American Guernsey Cattle Club shows that in a comparison of sires with ten or more tested daughters and their sons with tested daughters approximately 60 per cent of these sons increased the production of butter-fat of their daughters over their dams,

while the other 40 per cent lowered it. At the Maine Agricultural Experiment Station, Prof. J. W. Gowen has studied the transmitting qualities of Holstein-Friesian sires. In this study were included all Holstein-Friesian Advanced Registry sires with two or more tested daughters coming from tested dams. This included 111 bulls with two or more 365-day-test daughters from 365-day-test dams. Of the 111 bulls, 65 increased the milk yield of daughters over dams and 46 lowered it; 52 increased butter-fat percentage and 59 lowered it; 71 increased the net butter-fat and

FIG. 71.—Imp. Hayes Cherub 2d, founder of the Cherubs, an outstanding family of Guernseys.

40 decreased it. This shows that a random selection of bulls to use on test cows would be about as apt to give daughters that would produce less than their mothers as to give the sort that would produce more. This investigation showed also that sons of the same sire may raise, maintain, or lower their daughters' production.

The same type of investigation carried on in the Jersey breed at the Maine Agricultural Experiment Station showed that of 224 sires 105, or 46 per cent, raised milk production; 101, or 44 per cent, raised butter-fat per cent; and 99, or 44 per cent, raised the

net butter-fat of daughters over dams. The same data show that of 159 sires which could be compared to their sons in transmitting ability for milk and fat, 69 has sons which raised butter-fat production of their daughters over their dams, while 90 had sons which lowered it.

The above data all stress the fact that one cannot blindly submit to the statement that "like begets like." In a general way, it does, that is, cows produce calves and not pigs, but specifically it does not. It also stresses the point that there are strains or families inherently capable of better performance than the average because of the type of germplasm they carry, also that they are quite apt to pass this on to their offspring. If carefully controlled breeding investigations teach anything, it is that the only sure way to progress is through the progeny performance test. This means that the next head of the herd or flock must be chosen early and mated with a few animals of known capabilities and the resulting offspring studied to see whether this sire is apt to raise or lower the standard of the herd. This, of course, takes time, money, and hard work; however, one should early accept the fact that in the breeding of animals there is no short cut to success.

Future Possibilities.—It will readily be recognized that the number of animals in the most efficient strains is more or less limited. It is also a fact that because of their recognized merit there is a large demand for them, and they consequently sell for high prices. To the small breeder, this is discouraging, but he need not be without hope. These, to be sure, are proved strains, though when their origin is studied it is found that they arose more or less by chance through the mating of two particular individuals. Each parent probably supplied some previously missing factor or factors, which when combined into one individual yielded an animal of much greater worth than either parent and, moreover, an animal capable of transmitting its own qualities. It would be foolish to believe that what has occurred cannot be repeated. The small breeder with limited capital may, through a proper blending of strains, produce a strain more beautiful and more efficient than anything yet known. This does not mean that any breeder can be careless in selecting foundation stock nor need he, in general, expect to get something from nothing. He should, by all means, select from proved strains in as far as his finances will allow, because, as has been

shown, the isolation interpretation explains much more logically than does the mass-selection interpretation the progress that has been made in the past. When an outstandingly good animal arises from mating two more or less mediocre animals the progeny performances test must be very rigidly applied.

"Selection Indices."—In all selection work, as, indeed, in all practical breeding, it is necessary for the stockman to have his ideal thoroughly in mind. In the absence of such a definite ideal it is difficult to understand how any breeding operations can possibly have an orthogenetic trend. The requirements of efficient selection, therefore, demand, first, an accurate method of judging the comparative worth of a series of animals with respect to certain definite characters, and, second, a method of weighting different characters in the same individual according to their comparative value from a breeding standpoint. It is here that science may be expected to make definitely useful contributions to practical breeding methods in the determination of mathematically accurate means of comparing data.

With respect to the first point, the comparative value of a given character in a series of individuals, several factors must be considered. Only one definite case can be considered here, that of milk production in dairy cows. Obviously, with cows kept under identical conditions, two factors have a great influence on the amount of milk produced within a given period, namely, the age of the cow and the stage of lactation. Pearl has shown that the amount of milk produced by a cow within a given period is a logarithmic function of her age. His investigations further show that the curve of milk production with respect to age is of the general form

$$Y = a + bX + cX^2 + d \log X.$$

In this equation, Y denotes the amount of milk produced in a given time, X the age of the cow, and a, b, c, and d are constants the value of which must be calculated for different breeds. Stated in general terms, therefore, milk production increases with age until at about five years a maximum is reached, after which it decreases with advancing age. It is, of course, a matter of common experience that milk production decreases gradually during the lactation period. These two factors have been taken into account by Pearl in preparing a table of comparative efficiency percentages for dairy cows. In this table the maximum efficiency is set at 100 per cent and the comparative excellence at any given age or stage of lactation is given a value in per cent of this maximum value. Pearl has calculated such a table for twenty-four months, of which ten months only are given in Table XIX. This table provides a very satisfactory method of comparing a set of indi-

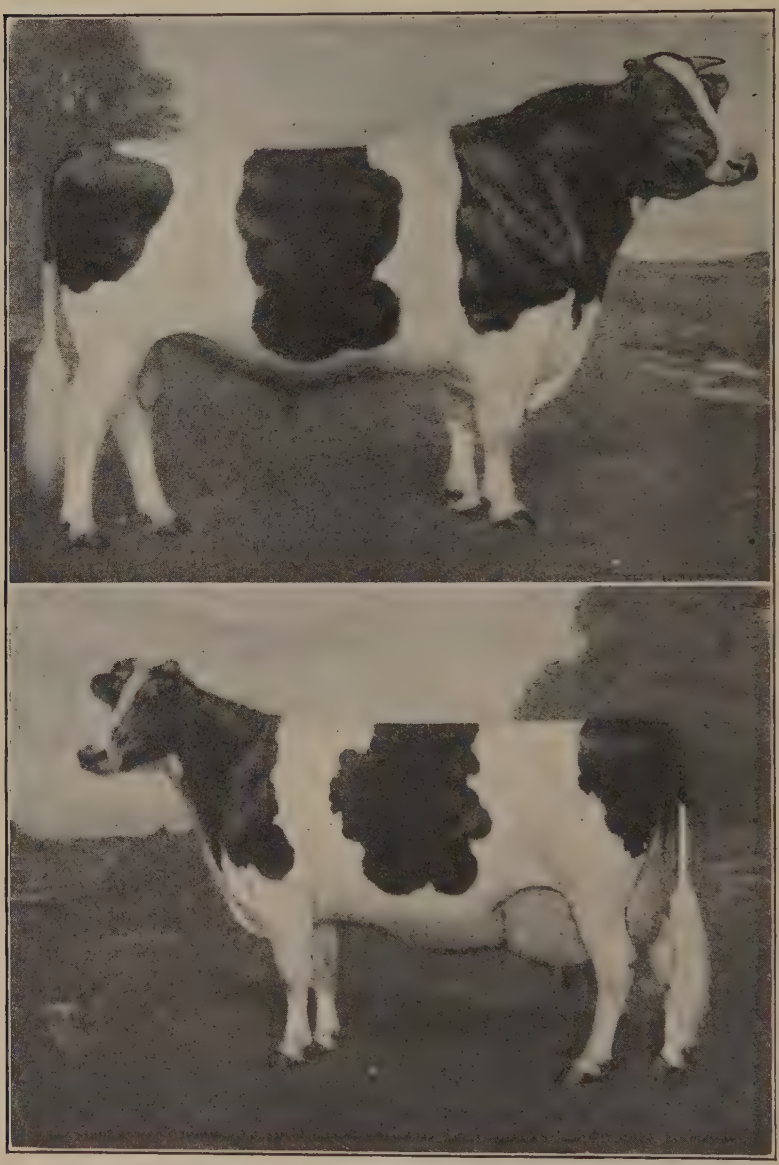


FIG. 72.—The "targets" at which Holstein breeders are shooting. Such models should prove invaluable in fixing type.

vidual records from cows of different ages and in different stages of lactation.

TABLE XIX.—EFFICIENCY PERCENTAGES FOR MILK PRODUCTION IN DAIRY CATTLE

(*Data after Pearl, from Babcock and Clausen*)

Age of cow in years and months	Months since freshening									
	1	2	3	4	5	6	7	8	9	10
1:6 – 1:11	58	54	51	47	44	41	37	34	30	27
2:0 – 2:5	73	69	64	60	56	52	48	43	39	35
2:6 – 2:11	82	77	72	67	62	57	52	47	41	36
3:0 – 3:5	89	83	77	71	66	60	54	48	43	37
3:6 – 3:11	93	87	81	75	69	62	56	50	44	38
4:0 – 4:11	97	91	84	78	71	65	58	52	45	39
5:0 – 5:11	100	93	86	79	72	66	59	53	46	39
6:0 – 6:11	100	93	86	79	72	65	58	52	45	38
7:0 – 7:11	99	92	85	78	71	64	57	51	44	37
8:0 – 8:11	97	90	84	77	70	63	56	50	43	37
9:0 – 9:11	94	88	82	75	69	62	55	49	43	36
10:00–10:11	91	85	79	73	67	61	54	48	42	36
11:00–11:11	88	82	76	71	65	59	53	47	41	35
12:00–12:11	85	80	74	68	63	57	52	46	40	35
13:00–13:11	82	76	71	66	61	55	50	45	39	34

The second difficulty has to do with determining some method by which selection may be made effective for a number of characters, or, in other words, a method of comparing different individuals with respect to a number of different characters. The use of selection index numbers provides a way of surmounting this difficulty. Pearl has made use of the following fundamental selection index in the Maine Station poultry work:

$$I_1 = \frac{5(a+b)}{c+d+1}$$

in which:

1 equals selection index number for a particular individual.

a equals percentage of eggs which hatched.

b equals percentage of eggs actually laid to the total number which might have been laid during the breeding season, Feb. 1 to June 1.

c equals percentage of infertile eggs.

d equals percentage of chicks which died within 3 weeks after hatching.

The application of this index to different hens in a breeding flock is shown in the Table XX. The selection index ranges in value from

2.8 to 45.2, those birds having the highest breeding value which have the highest selection index. By this method it is possible to substitute for a vague personal impression of breeding value an exact numerical expression which is an accurate measure of the breeding value of any individual. It is possible to devise such selection index numbers for other purposes, and they should prove of utility in practical breeding operations."[1]

TABLE XX.—SELECTION INDICES FOR BARRED PLYMOUTH ROCK PULLETS
(*Data of Pearl and Surface*)

Band number	*a*	*b*	*c*	*d*	1_1	Band number	*a*	*b*	*c*	*d*	1_1
10	21	18.33	36.0	33.33	2.8	29	28	28.33	27.0	0	10.0
160	9	15.83	42.0	0	2.9	23	39	35.83	28.0	8.33	10.0
402	14	33.33	30.0	50.0	2.9	428	46	40.08	20.0	22.22	10.0
352	12	41.67	14.0	60.0	3.6	122	49	34.17	15.0	23.53	10.5
358	50	31.67	32.0	69.23	4.0	375	41	37.50	36.0	0	10.6
438	35	35.00	45.0	37.50	4.2	712	42	50.00	20.0	20.00	11.2
441	38	20.00	33.0	33.33	4.3	408	48	45.86	16.0	22.73	11.8
21	25	35.00	14.0	44.44	5.0	38	61	37.50	9.0	28.00	13.0
393	12	47.50	9.0	50.00	5.0	731	27	35.83	23.0	0	13.1
705	38	26.67	34.0	25.00	5.4	395	29	37.50	24.0	0	13.3
717	24	21.67	19.0	20.00	5.7	443	56	54.17	6.0	35.29	13.3
39	23	29.17	26.0	16.67	6.0	409	37	46.67	4.0	25.00	13.9
377	32	37.50	16.0	33.33	6.9	771	43	60.00	13.0	22.22	14.2
746	59	28.33	15.0	47.06	6.9	19	68	24.17	24.0	6.66	14.5
87	36	39.17	17.0	35.71	7.0	152	26	39.17	11.0	9.09	15.5
359	61	32.50	15.0	50.00	7.1	366	52	25.83	13.0	7.14	18.4
442	41	68.33	38.0	28.57	8.2	768	74	45.00	20.0	9.38	19.6
400	44	47.50	16.0	38.10	8.2	434	72	58.33	17.0	14.28	20.2
27	18	40.00	8.3	25.00	8.5	750	57	52.50	16.0	10.00	20.3
757	23	51.67	10.0	30.77	8.9	770	71	50.83	9.8	12.82	25.8
725	33	29.17	6.0	27.27	9.1	752	48	59.17	6.0	12.50	27.5
112	17	46.67	18.0	25.0	9.3	397	38	40.00	6.0	5.89	30.3
753	61	47.50	46.0	10.53	9.4	168	88	35.83	4.7	13.89	31.6
407	41	41.67	18.0	23.53	9.7	749	57	46.50	4.0	6.45	45.2

Selection Index for Swine.—The following card system has been installed with the swine herds at the Massachusetts Agricultural College for the purpose of furnishing a selection index.

[1] BABCOCK and CLAUSEN, Genetics in relation to agriculture, pp. 502–505, McGraw-Hill Book Company, Inc., 1918.

M. A. C. 44
Born: May 23, 1922
Breeder: Massachusetts Agriculture College
Sire: Dulcette's Prince 3rd
Dam: Brocktonia's Queen 3rd

Litter:[1] $\frac{5}{6}$ $\frac{4}{4}$

Score as individual..... 82.0
Score as to fertility..... 100.0
Score as mother..... 87.5
Score as milker..... 96.5

BREEDING RECORD

1924 Bred to	Date bred	Date farrowed	Gestation	Litter data	Per cent raised	Average weight at birth	Average weight 8 weeks	Per cent growth	Remarks
A. M.....	Dec. 29	Apr. 22	115	$\frac{3}{3}$ $\frac{4}{5}$	87.5	2.37	29	96.5	2 ruptured pigs

[1] The denominators of these fractions indicate the number of boars and sows farrowed n the litter and the numerators the number weaned. This fraction gives an idea as to the motherly qualities exhibited in the dam of this sow.

FIG. 73.—Selection index card system for swine.

It is evident from the above that this two-year-old sow had in her litter three boars and five sows, of which she raised three boars and four sows. This gives her a percentage efficiency of 87.5 per cent as a mother. An arbitrary standard has been set, namely, that by the time the pigs are 8 weeks old they should reach 30 pounds. This sow was able to get her pigs to a weight of 29 pounds and her score as a milker is therefore 96.5 per cent. An arbitrary standard has also been set for the number of pigs per litter for which sows of varying ages are to be held accountable. This standard is as follows:

Up to one year of age..... six pigs per litter
Up to two years of age..... seven pigs per litter
After two years of age..... eight pigs per litter

This two-year-old sow farrowed eight pigs, so received a score of 100 per cent as a breeder, and she has already been penalized in her score because one pig died before weaning age. The individuality of the sows is considered and they are scored by means of an ordinary score card. This sow scored 82 per cent in this respect. A general selection index is secured for each sow by totaling the four scores and extracting the average.

	PER CENT
Individuality.....	82.0
Fertility.....	100.0
Milking qualities.....	96.5
Motherly qualities.....	87.5
	4)366.0
	91.5, general selection index

It is, of course, possible and advisable to set limits in any of the above phases of swine breeding below which animals will not be allowed to fall and still remain in the breeding herd, *e.g.*, a lower limit of 80 per cent in individuality. The general selection index can be set at any desired lower limit to start with and then be raised from year to year as the results of selection make this possible. For instance, it could be assumed that any sow which did not show a general selection index of at least 85 per cent for this year would be discarded from the breeding herd and probably in a few years' time this lower limit could be moved up to 90 or higher.

Other Selection Indices.—The yearly production of offspring, their general type together with production records, furnishes a good general selection index in dairy cattle and for beef cattle as well if the milk production be measured in terms of how fast the calf grows. The same general plan will hold for breeding ewes in which class of livestock the birth weight of lambs, their weight at three or four months, the wool clip of ewe, and the individual score of ewe will furnish the criteria for arriving at a selection index figure. It would seem advisable to give extra credit in sheep for the production of twins.

Records versus Judging in Selection.—An investigation by Gowen of the Maine Agricultural Experiment Station is of peculiar interest. The following figure shows the relative efficiency of even short records of production as indicators of yearly production as compared to the total score of the animal and the score in several respects commonly believed to be indicators of productive capacity.

Pausing to consider briefly these facts we see that a seven-day test might be considered as an objective test, whereas the value of the points of conformation are a subjective test for the cow's producing ability. That is, the seven-day test is simply dependent on the reading of the scales that weigh the milk, whereas the use of scale of points to judge a cow for milk yield depend, not on any external scale, but on the mental processes or mental ability of the judge so to balance his cuts as to show the true worth of the cow. From this it follows that the conformation of the cow as a measure of milk yield would in all probability be subject to the personal bias of the judge.

This is, in fact, shown to be the case on study of the records. There are nineteen men, all well-trained dairymen, who have judged enough cattle with milk yield to make a test of their ability as judges of these

cows for milk yield. Nine of these men clearly could judge dairy cattle by the score card and select the better milkers. On a scale ranging from 1 to 0 and 0 to −1 (correlation scale) these men varied from the most accurate judge of milk yield from the conformation of 0.614 to the least accurate judge of −0.098. The average ability of these men is 0.246, or they are, on the average, about 25 per cent better judges of dairy cattle for milk production than the average trained dairymen. Clearly, some men are good cattle judges. Equally clearly, some men cannot judge cattle for milk production by the use of the score card. Such being the case, the individual man will do well before he selects cattle by their conformation alone to make a sufficient test to convince himself that he is one of those gifted men who can judge dairy cattle.

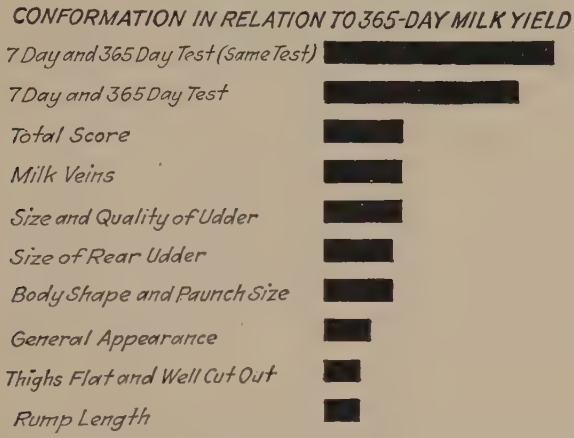

CONFORMATION IN RELATION TO 365-DAY MILK YIELD
7 Day and 365 Day Test (Same Test)
7 Day and 365 Day Test
Total Score
Milk Veins
Size and Quality of Udder
Size of Rear Udder
Body Shape and Paunch Size
General Appearance
Thighs Flat and Well Cut Out
Rump Length

FIG. 74.—The length of the black bars indicates the relative value of the different points as measures of milk producing capacity. (*After Gowen.*)

On the other hand, almost anyone can weigh milk. No personal equation need be present in recording the weights. Such being the case, when they are obtainable the dairymen or buyer would do well to consider the milk yield carefully in selecting dairy cows as indicated by the figures above.[1]

Conclusion on Selection.—Rational selection of animals for a breeding herd will, therefore, include the following considerations: The class, type, and breed of animal calculated to return the greatest profit; likelihood of fertility and vigor through inheritance and conformation; uniformity in the animals with balancing of faults in males and females and as high individual

[1] GOWEN, J. W., Report of progress on animal husbandry investigation, *Maine Agr. Exp. Sta. Bull.*, 299, pp. 87–88, 1921.

excellence as possible in all animals; intimate knowledge of breed history past and present, so that pedigrees may be properly evaluated and blood lines blended; ruthless weeding out of those individuals who through themselves or their progeny do not raise average production; making the progeny performance test the final court in passing sentence on an individual's worth in the herd or flock; development and use of a selection index whenever possible; realization that the best in the breeds is concentrated in a few outstanding individuals, strains, or families.

CHAPTER XVII

BREED ANALYSES—HERD SYNTHESES

It is important to analyze the production and show-yard records of the leading animals in several breeds of livestock.[1] Such an analysis should bring to light the animals, strains, and families, in the breeds examined, which have contributed most to the recent progress of each. The methods of breeding will also be revealed by pedigree studies. Theoretically, the best animals in any breed are those that show the highest combined score for type and production. It should be borne in mind, however, that many high-producing cows are never put on test, many show-yard winners are never tested, many high-producing cows are never exhibited, and that poor feeding and management often curtail an animal's production. In other words, these analyses are not supposed to be infallible nor to constitute the last word in assigning merit. They are simply one interpretation of the facts as they are found.

Analysis of Jersey Class Leaders.—The ten leading animals in each of the nine classes of the Jersey breed as of Nov. 1, 1924, furnished the material for this study. Complete four-generation pedigrees of these animals were secured. From this material the following tables have been compiled. All of the bulls occurring in these pedigrees were listed and each bull given a score of 4 when he was the immediate sire of the class leader, a score of 3 when the bull occurred in the second generation, a score of 2 when he occurred in the third generation, and a score of 1 when the occurrence was in the fourth generation. The following table shows: (1) the rank of the 47 bulls scoring 10 or more (plus four bulls which scored 8 as immediate sires of two different class leaders), (2) the number of appearances each bull has in each of the four generations, (3) the total number of appearances of each bull in these ninety four-generation pedigrees, and (4) the bulls' individual scores on the basis outlined above.

[1] Malin, D. F., "The evolution of breeds," for analyses of beef and swine breeds, Wallace Publishing Company, Des Moines, Iowa, 1923.

TABLE XXI.—SCORES OF BULLS IN PEDIGREES OF JERSEY CLASS LEADERS

Name	Rank	Scoring	Number of appearances in pedigrees	Total score
Hood Farm Torono	1	2–9–6–8	25	55
Rosaire's Olga Lad	2	1–5–16–2	24	53
Golden Glow's Chief	3	4–4–8–4	20	48
Pogis 99 of Hood Farm	4	7–3–2–0	12	41
Hood Farm Pogis 9th	5	0–8–5–4	17	38
Rinda Lad of S. B	6	4–5–3–0	12	37
Pride's Olga 4th Son	7	0–3–7–12	22	35
Torono	8	0–2–9–9	20	33
St. Mawes' Lad	9	7–1–0–0–	8	31
Chief Engineer	10	0–4–4–10	18	30
Gertie's Lad	11	0–5–5–5	15	30
Fort Hill Farm Chief	12	1–0–9–7	17	29
Rosaire's Golden Lad	13	0–0–8–12	20	28
St. Mawes	14	0–1–4–16	21	27
Poppy's St. Mawes	15	0–7–1–0	8	23
Sophie's Tormentor	16	0–0–3–17	20	23
Hood Farm Pogis	17	0–0–8–6	14	22
Spermfield Owl	18	1–0–7–3	11	21
Gertie's Son	19	0–0–4–12	16	20
Mistletoe Pogis	20	0–2–5–2	9	18
Noble of Oaklands	21	0–1–4–7	12	18
Sophie 19th Tormentor	22	2–3–0–0	5	17
Tormentor	23	0–0–2–13	15	17
Eminent	24	0–2–3–4	9	16
Imp. Golden Maid's Prince	25	0–4–2–0	6	16
Champion Torono's Son	26	0–3–3–0	6	15
Interested Prince	27	0–1–4–4	9	15
Noonan's Don Pogis	28	0–0–4–5	9	13
Phyllis	29	0–2–3–1	6	13
The Owl	30	0–2–2–3	10	13
Brown Bessie's Diploma	31	0–0–4–4	8	12
Fannie's Prince	32	3–0–0–0	3	12
La Belle's Oxford Lad	33	0–4–0–0	4	12
Merry Maiden's Son	34	0–1–0–9	10	12
Philosopher	35	0–1–0–9	10	12
Reminder	36	0–0–4–4	8	12
Sayda's Heir	37	1–1–2–1	5	12
G. G. Chief of Ashburn	38	0–3–1–0	4	11
Eminent's Raleigh	39	0–1–2–4	7	11
Imp. Golden Fern's Lad	40	0–0–3–5	8	11
Oxford You'll Do, Jr	41	0–1–4–0	5	11
Pride's Olga 3rd King	42	2–1–0–0	3	11
King of Arden	43	0–0–4–2	6	10
Mabel's Raleigh	44	0–1–2–3	6	10
Oonan's Pogis	45	0–0–1–8	9	10
Stoke Pogis of Prospect	46	0–0–0–10	10	10
The Imported Jap	47	1–0–3–0	4	10
Eminent's Pilot	..	2–0–0–0	2	8
Heir of Crystal Spring	..	2–0–0–0	2	8
St. Mawes of Ashburn	..	2–0–0–0	2	8
St. Helier's Lad of Ingleside	..	2–0–0–0	2	8

There was a possibility of finding 1,245 different bulls in these pedigrees (7 *repeats*). The actual number of different bulls found was 520. There were 47 bulls that scored 10 or more. These 47 bulls sired 36 of the 90 class leaders, or 0.77 each. Four other bulls sired two class leaders each. The other 469 bulls occurring in these pedigrees sired 46 class leaders, or 0.09 each.

The following are among the leading families in the Jersey breed: *Golden Lad*, Eminent, Raleigh, Oxford, Flying Fox, Majesty, Gamboge, Owl Interest, *Stoke Pogis*, St. Mawes, Sayda's Heir, St. Lambert, *Tormentor*. The foregoing list of 47 high-scoring bulls can practically all be roughly classified into three main families, namely, the Golden Lad, Stoke Pogis, and Tormentor.

TABLE XXII.—CLASSIFICATION OF HIGH-SCORING JERSEY BULLS

FAMILY	BULL'S NUMBERS
Golden Lad.....	2, 3, 6, 10, 11, 12, 13, 18, 21, 23, 25, 30, 31, 32, 33, 34, 37, 38, 39, 40, 41, 44, 47
Stoke Pogis.....	2, 4, 5, 6, 7, 9, 11, 14, 15, 17, 19, 20, 28, 29, 35, 42, 45, 46
Tormentor.....	1, 4, 5, 8, 12, 16, 22, 23, 27, 35

There are commonly said to be two types of Jersey cattle—the Island type, noted for its symmetry and smoothness of form, and the American type, noted for production. As a matter of fact, all Jersey cattle are Jersey cattle and have descended from cattle native to the island of that name. Some breeders have selected primarily for beauty of form, others have selected primarily for production. The efforts of each group have met with a very great degree of success in their respective fields. The ideal dairy animal will be one which combines both beauty of form and efficiency of function. While it is foolish to question the existence of a certain amount of correlation between type and production and between production and type, a far safer and speedier way to move on toward the ideal is to select for both type and production at the same time, and not trust that one necessarily implies the other to any great degree.

The following table shows: (1) the rank of the forty-two cows scoring 7 or more, (2) the number of appearances each cow has in each of the four generations, (3) the number of appearances of each of these cows in the ninety four-generation pedigrees, and (4) the cow's individual scores on the basis outlined above for the bulls.

TABLE XXIII.—SCORES OF COWS IN PEDIGREES OF JERSEY CLASS LEADERS

Name	Rank	Scoring	Number of appearances in pedigrees	Total score
Sophie 19th of Hood Farm	1	0–9–7–2	18	43
Phils Scituate	2	1–0–9–7	17	29
Tormentor's Lass	3	0–2–8–7	17	29
Golden Glow	4	0–4–4–7	15	27
Anna Rosaire	5	0–1–6–12	19	27
Rinda Sunny Bank	6	0–4–5–3	12	25
St. Mawes' Beauty	7	0–7–1–0	8	23
St. Mawes' Poppy	8	0–2–8–1	11	23
Figgis	9	0–0–8–5	13	21
Gertie of Glynllyn	10	0–0–5–11	16	21
Hood Farm Le Gros 2nd	11	2–3–1–1	7	20
Lass No. 66 of Hood Farm	12	3–1–1–0	5	17
Pride's Olga 4th	13	0–0–3–10	13	16
Rhoda Hudson	14	0–0–3–9	12	15
St. Mawes' Lucy	15	0–0–7–1	8	15
Lad's Lady Ann	16	3–1–0–0	4	15
Mistletoe's Melia Ann	17	1–3–1–0	5	15
Hood Farm Le Gros	18	0–2–3–1	6	13
Rinda's Double Rex	19	0–0–4–5	9	13
Susy of Forestdale	20	0–0–2–9	11	13
Addie P	21	0–0–2–8	10	12
Lady Jane Grey 2nd	22	0–0–4–4	8	12
Susy of Forestdale 2nd	23	0–0–2–8	10	12
Sophie Hudson	24	0–1–0–9	10	12
Scituate Beauty D	25	0–1–0–9	10	12
Sugar-in-the-Barrel	26	3–0–0–0	3	12
Sulphide	27	0–0–4–4	8	12
La Belle Siberieuse	28	0–1–4–0	5	11
Birdie La France	29	0–3–0–1	4	10
Governor's Olga Ann	30	0–1–3–1	5	10
Golden Maid	31	0–0–4–2	6	10
Kathletta's Fancy	32	0–0–1–8	9	10
Spermfield Lassie	33	0–1–0–7	8	10
Brown Bessie Marine	34	0–0–2–5	7	9
Fauvics Empress	35	0–3–0–0	3	9
Hood Farm Fox's Figgis	36	0–0–3–3	6	9
Birdseys Suprise	37	0–0–0–8	8	8
Betty's Lady Fern	38	2–0–0–0	2	8
Empress La Belle	39	2–0–0–0	2	8
Gertie's Melia Ann	40	0–0–1–6	7	8
Golden Lad's Rosaire	41	0–0–0–8	8	8
Koneta's Lady	42	2–0–0–0	2	8
Lady Molly Moore	43	2–0–0–0	2	8
Lass 47 of Hood Farm	44	2–0–0–0	2	8
Pride's Olga 3rd	45	0–2–1–0	3	8
Ventnor Beauty Belle	46	1–1–0–1	3	8
Old Man's Darling	47	1–1–0–0	2	7
Exile's Rosebud	48	0–1–1–2	4	7
Eminence	49	0–0–2–3	5	7
Governor's Betty	50	0–2–0–1	3	7
Isleta Le Gros	51	0–0–2–3	5	7
Josy's Glow	52	0–0–3–1	4	7
Lady Viola	53	0–0–1–5	6	7
Mayflower of Pitts	54	0–0–2–3	5	7
Murial of A 2nd	55	0–0–3–1	4	7
Sayda's Princess	56	0–1–1–2	4	7

In these 83 pedigrees (7 *repeats*) there might have been found 1,245 different cows. The actual number of different cows found was 735. The number of different bulls found was 520. In other words, there are 41 per cent more different cows than different bulls in these pedigrees. This is to be expected, as bulls are generally more carefully selected than cows and bulls can be used more extensively in breeding and leave many more offspring than cows. There were 56 cows that scored 7 or more. These 56 cows were the dams of 25 of the 90 class leaders, or 0.44 each. The other 679 cows occurring in these pedigrees were the dams of the remaining 65 class leaders, or 0.09 each.

The two tables show clearly the animals which have been used most extensively in the production of the class leaders.

Inbreeding and Relationship Values in Jersey Class Leaders.—These pedigrees were also studied for their inbreeding (Z) and relationship (K) values. These are given in Table XXIV.

This table illustrates that fifty-four of these class leaders show some inbreeding up to and including the fourth generation. In other words, 60 per cent of these animals are inbred to some extent, while 40 per cent are not inbred up to and including the fourth generation. Seven of these animals are inbred in the Z_1 or second generation. The average amount of inbreeding shown by the whole of the ninety class leaders is 8.3 per cent of the greatest amount possible, *i.e.*, continued brother and sister matings. Forty-six per cent of the animals that are inbred also show relationship values (K), indicating that the same animal or animals being used to produce the inbreeding occur on both the sires' and the dams' sides of the pedigrees in this percentage of the cases. In the other 54 percent of cases the repeating animals are confined to one or the other side of the pedigree. The greatest amount of inbreeding is shown by Owl Interest Mermaid. Her pedigree is of interest and is shown on page 227. The two grandsires are the same animal, the Owl's Duke. The four great grandsires are the same animal, Spermfield Owl. Instead of having four new and different great granddams, this animal has only three, the Duke's Dorothy being repeated. Among the great greatgrandsires the Owl must necessarily appear four times as the sire of Spermfield Owl. This means that four other sires might be found in this fourth generation, but it is seen that Theda's Duke of Portage and Interested Prince each occur twice. Spermfield Lassie must appear four times in the

TABLE XXIV.—INBREEDING AND RELATIONSHIP VALUES IN JERSEY CLASS LEADERS

Number	Name	Registration number	Z_1	Z_2	Z_3	Z_{t_3}	K_1	K_2	K_3
1	St. Mawes' Lad's Lady	451568	0	12.5	18.75	14.7	0	0	0
2	Lulu Alphea of Ashburn	375710	0	12.5	18.75	14.7	0	0	0
3	St. Mawes' Lad's Ruby	485715	0	12.5	18.75	14.7	0	0	0
4	St. Mawes' Lad's Pride	515044	0	12.5	18.75	14.7	0	0	0
6	Oxford's Flower Girl	418079	0	0	6.25	3.0	0	0	0
7	St. Mawes' Lad's Susy	517340	25	37.5	50	53.0	50	50	50
9	St. Mawes' Lad's Girlie	469502	0	25	31.25	26.4	0	0	0
10	Lucky Farce	.....	0	12.5	18.75	14.7	0	25	25
13	Pearly Exile of St. Lambert	205101	0	0	6.25	3.0	0	0	0
14	Sophie's Bertha	313238	0	0	6.25	3.0	0	0	12.5
16	Prince Darling's Fritzie	443318	0	12.5	12.5	11.3	0	0	0
17	St. Mawes' Lad's La Belle	469501	0	12.5	18.75	14.7	0	0	0
18	Sophie's Emily	352291	0	0	6.25	3.0	0	0	12.5
19	Lass 66 of Hood Farm	271896	0	0	6.25	3.0	0	0	0
20	Royal Majesty's Dahlia	483549	0	0	12.5	5.9	0	0	0
21	St. Mawes' Pretty Lady	432698	0	12.5	18.75	14.7	0	25	37.5
22	Empress Lass of Ingleside	458887	25	25	25	35.3	50	50	50
23	Irene's Cherry	285828	0	0	6.25	3.0	0	0	12.5
25	Sophie's Honeysuckle	445729	25	25	31.25	38.0	50	50	62.5
26	Chieftain's Flora	389619	0	0	12.5	5.9	0	0	12.5
27	Koneta's Lady 2nd	396741	0	12.5	18.75	14.7	0	0	0
30	St. Mawes' Dame Lavina	.....	0	0	6.25	3.0	0	0	0
33	Poet's Mabel Mowat	479804	0	12.5	12.5	11.3	0	0	0
34	Sophie Torono's Hester	431506	0	12.5	12.5	11.3	0	25	25
36	Sophie's Bertha	313238	0	0	6.25	3.0	0	0	12.5
37	Ayerdale's Over-the-Top	419983	0	0	6.25	3.0	0	0	0
38	Atlanta's Noble Helen	502292	0	12.5	12.5	11.3	0	0	0
39	Clara Lettie of Ashburn	368366	0	12.5	18.75	14.7	0	0	0
40	Countess Stella of Ashburn	355367	0	0	6.25	3.0	0	0	0
42	Empress Lass of Ingleside	458887	25	25	25	35.3	50	50	50
43	Lass 66th of Hood Farm	271896	0	0	6.25	3.0	0	0	0
45	Birdie Owl of M. L. P.	415227	0	12.5	12.5	11.3	0	0	0
46	Lady's Silken Glow	313311	0	12.5	18.75	14.7	0	0	0
47	Sophie's Bertha's Son Edith	513951	25	25	43.75	44.1	50	50	50
48	R. F. S. Sophie's Lora	450112	0	0	6.25	3.0	0	0	0
50	Sophie's Tormentor's Isadora	445756	0	0	12.5	5.9	0	0	25
51	Darling's Jolly Lassie	435948	0	12.5	12.5	11.3	0	25	25
52	St. Mawes' Lad's Lady	451568	0	12.5	18.75	14.7	0	0	0
53	Old Man's Darling 2nd	319617	25	25	25	35.3	50	50	50
54	Lad's Little Pauline	349277	0	0	12.5	5.9	0	0	12.5
57	Owl Interest Tulip	474283	0	25	25	23.5	0	25	25
59	Sophie's Adora	299594	0	0	6.25	3.0	0	0	12.5
62	Fair Play's Princess	438792	0	0	6.25	3.0	0	0	12.5
64	Tonona's Jean of H. S. F	425602	0	0	12.5	5.9	0	0	0
65	Owl Interest Mermaid	390025	25	50	56.25	61.7	50	75	87.5
66	Sophie's Forest Queen	387414	0	12.5	18.75	14.7	0	25	37.5
68	Sophie's Tormentor's Elinda	376896	0	12.5	12.5	11.3	0	25	25
69	Koneta's Lady 2nd	396741	0	12.5	18.75	14.7	0	0	0
72	Princess Emma of H. S. F	359390	0	0	6.25	3.0	0	0	0
73	Lad's Iota	350672	0	0	6.25	3.0	0	0	12.5
74	Madeline of Hillside	389336	0	0	6.25	3.0	0	0	0
77	Lady's Silken Glow	313311	0	12.5	18.75	14.7	0	0	0
81	Snip Wauger 2nd	243040	0	12.5	12.5	11.3	0	0	0
86	King's Barbara K	257097	0	12.5	31.25	20.6	0	25	50

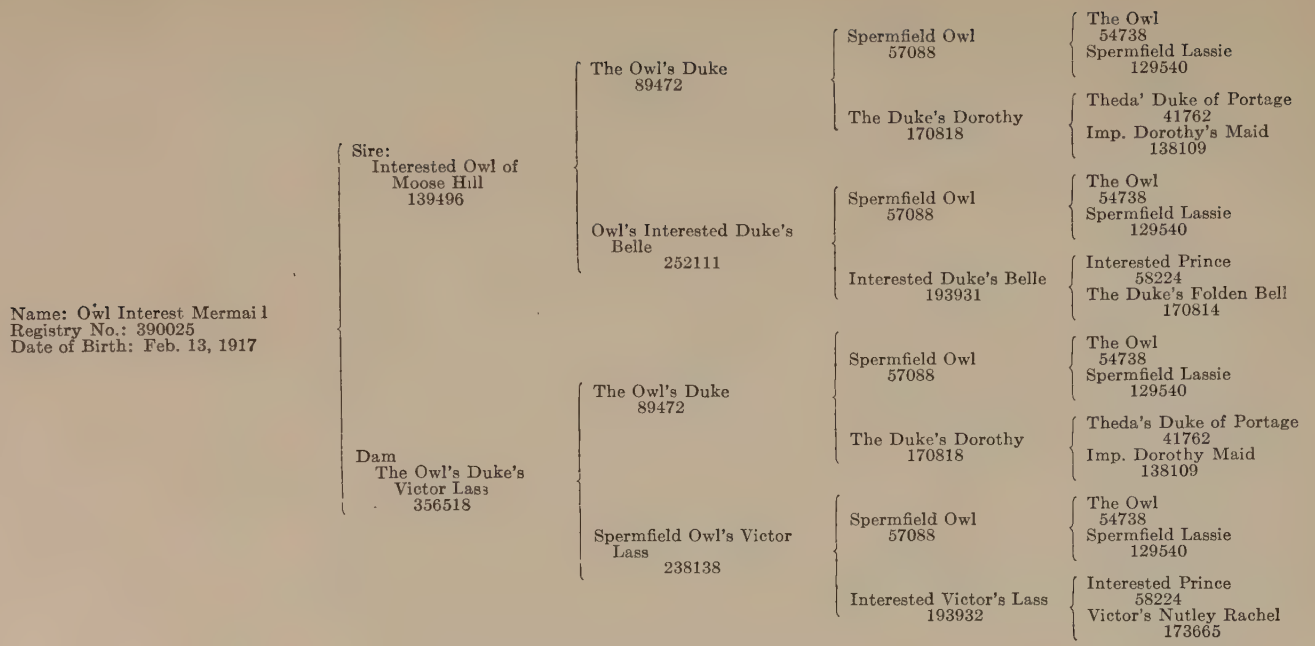


Fig. 75.—Pedigree of Owl Interest Mermaid.

great grandparental generation as the dam of Spermfield Owl. This means that four other cows might be found in this fourth generation, but as a matter of fact only three are found, Imp. Dorothy Maid occurring twice.

The Z values (inbreeding) and K values (relationship) of Owl Interest Mermaid are shown in the next table compared to continued brother-sister mating values.

TABLE XXV.—Z AND K VALUES OF OWL INTEREST MERMAID COMPARED TO CONTINUED BROTHER-SISTER MATINGS

	Z_1	Z_2	Z_3	Z_{t_3}	K_1	K_2	K_3
Owl Interest Mermaid.....	25	50	56.25	61.7	50	75	87.5
Continued brother-sister mating..	50	75	87.50	100.0	100	100	100

Maine Experiment Station Studies of Jersey Cattle.—At the Maine Agricultural Experiment Station the register of merit records of the Jersey breed was the subject of an investigation to ascertain which bulls in the breed had a tendency to raise the milk, fat percentage, and net butter-fat of their daughters over the dams of these daughters, and which bulls had a tendency to lower these items. The following table from this report[1] shows the bulls which increased both milk and butterfat percentage of their daughters. Only sires were considered which had two tested daughters coming from tested dams, yearly tests alone considered.

[1] PEARL, R., GOWEN, J. W., and MINER, J. R., Transmitting qualities of Jersey sires for milk yield, butterfat percentage, and butterfat, *Maine Agr. Exp. Sta. Bull.* 281, 139 pp., 1919.

TABLE XXVI.—BULLS WHICH INCREASED BOTH MILK AND BUTTERFAT PERCENTAGE OF THEIR DAUGHTERS

(After Pearl, Gowen, and Miner)

Number	Name	Registry number	Number of pairs	Net increase		
				In milk, pounds	In fat, per cent	In net fat, pounds
1	Signal's Successor	72758	3	2,899.3	0.202	177.72
2	Golden Glow's Chief	61460	4	2,172.4	0.453	161.93
3	Hood Farm Pogis 34th	63300	2	2,528.0	0.044	159.24
4	Tormentor's Landseer Signal	69291	4	2,326.7	0.292	153.55
5	Clear Brook Chief	74685	2	278.0	1.338	153.31
6	Channel King	62762	2	2,332.0	0.148	150.30
7	Majestic Fern	84428	3	2,163.3	0.123	143.97
8	Golden Fern's Son ...../	78687	9	1,156.5	0.458	109.32
9	Spermfield Owl	57088	26	1,695.7	0.027	97.71
10	Sultan of Oaklands	P. S. 3746	3	1,104.7	0.385	95.06
11	Chenille's Golden Prince	91769	2	1,242.0	0.264	93.06
12	Eurybia's Blue Boy	90591	3	1,170.3	0.253	90.17
13	Roiter's Jersey Lad	58001	7	1,415.2	0.019	87.10
14	Pogis 99th of Hood Farm	94502	14	995.2	0.230	82.34
15	Jenny's Redfern	70388	2	1,582.0	0.030	79.56
16	Mabel's Raleigh	P. S. 3722	3	1,078.0	0.133	70.51
17	Pogis 66th of Hood Farm	85015	3	514.7	0.385	66.86
18	Nebraska Lad	71828	2	296.5	0.439	57.14
19	Hood Farm Pogis 9th	55552	39	448.9	0.243	47.49
20	Blue Belle's Gold Fern	79043	3	429.4	0.139	37.08
21	Keepsake's Golden Lad	71325	5	165.2	0.244	32.18
22	Nutley Tones Owl	67837	3	259.0	0.174	30.55
23	Flying Fox's Oxford Duke 2nd	76316	2	372.5	0.100	29.30
24	The Owl of Meridale	85853	5	66.2	0.218	24.17
25	Eminent 4th	76078	5	237.8	0.084	21.54
26	Sayda's Heir 3rd	74817	15	106.5	0.166	20.87
27	Storr's Golden Lad	68189	2	33.0	0.078	9.80
28	Valentine's Oonan	58075	10	23.0	0.048	5.19

It is of interest to note that five of these bulls which increased production of daughters over dams are also found as high-scoring animals among the bulls which occur in the pedigrees of the ninety Jersey class leaders. These bulls are Nos. 2, 9, 14, 16, and 19 of Table XXI.

Table XXVII shows those bulls which decreased both milk and fat percentage:

TABLE XXVII.—BULLS WHICH DECREASED BOTH MILK AND FAT PERCENTAGE

(After Pearl, Gowen, and Miner)

Number	Name	Registry number	Number of pairs	Net decrease		
				In milk, pounds	In fat, per cent	In net fat, pounds
1	Gertie's Son of Washington	83799	3	2,593.4	0.619	227.01
2	Jubilee of Bois D'Arc	29041	3	1,542.3	0.810	162.92
3	Oonan 23rd's Grandson	74887	3	2,031.3	0.323	156.92
4	St. Helier of Sheomet	61765	3	1,874.0	0.400	150.59
5	Lady Mary's Fox	82763	2	2,236.5	0.268	148.02
6	Combination Golden Lad	59292	3	2,032.3	0.299	138.06
7	Harry B. Gordon	47246	2	1,989.0	0.138	124.46
8	Financial Raleigh	86298	4	1,092.0	0.554	115.05
9	Mona Rose's Glory	92531	5	1,550.4	0.270	110.94
10	Gertie's Son's Boy	71825	2	1,328.0	0.324	106.18
11	Fort Hill Farm Torono	72940	2	1,079.0	0.455	102.25
12	Brown Lassie's Compass	71626	5	869.6	0.604	100.61
13	Minaret Exile	56933	9	851.0	0.574	100.59
14	Noble Peer	90653	4	1,431.3	0.152	98.85
15	Tormentor's Torono	78184	5	1,245.4	0.256	90.51
16	H. F. Golden Fern's Lad	80437	7	1,048.7	0.361	90.49
17	Fad	85670	2	1,318.5	0.074	85.61
18	Pedro of Brick House Farm	88867	3	883.7	0.295	82.31
19	St. Mawes	72053	2	1,196.5	0.064	78.44
20	Fontaine's Duke	61709	6	861.7	0.275	76.54
21	Pogis 94th of Hood Farm	90492	2	1,038.5	0.215	75.91
22	Island Lodestar	67638	6	350.4	0.563	70.89
23	Golden Paul	68919	3	457.0	0.450	68.05
24	Inez's Stoke Pogis	51942	4	539.5	0.339	66.65
25	Lord North	75342	2	830.5	0.249	65.98
26	Golden Laddie of C	67925	3	889.7	0.170	65.75
27	Roving Gipsy	67588	2	599.5	0.355	64.75
28	Eminent 10th	75753	9	599.0	0.346	60.15
29	Altama's Pogis	77089	3	615.7	0.217	53.31
30	Mistletoe Pogis	75371	2	826.5	0.044	53.30
31	Biltmore's Torment	60761	4	165.5	0.492	50.61
32	Rosaire's Lad of Glenwood	76580	2	505.0	0.198	48.79
33	Imp. King of Hambie	65298	2	43.5	0.599	48.02
34	Olga Hazel Pogis	95042	2	698.5	0.094	46.97
35	Hood Farm Torono 20th	82854	19	682.9	0.072	45.59
36	King Allie Roiter	62221	2	639.5	0.115	45.11
37	Sultana's Oxford Lad	76506	3	292.0	0.267	40.77
38	Prince Ramaposa	87833	2	537.0	0.128	39.83
39	Gertrude's Jap	93947	2	542.0	0.080	38.47
40	Fairy Glen's Raleigh	79438	5	191.8	0.291	38.32
41	Reservation Stoke Pogis	76048	5	378.0	0.211	37.98
42	Mabel's Poet	65780	5	161.6	0.310	36.33
43	Seven Gates	75925	5	115.2	0.260	29.25
44	Meridale Interested Prince	86473	6	438.4	0.014	26.55
45	Merry Miss' Son	76629	5	95.6	0.221	26.17
46	Fontaine's Caiest	81118	5	142.8	0.077	15.01
47	Prince Noel	74140	4	8.8	0.148	13.04

Here it is of interest to note that with practically twice the opportunity to appear in this table (forty-seven animals as compared to twenty-eight) than in the former less than one-half as many animals which showed themselves as high scorers in the pedigrees of the class leaders do appear. There are two of these animals, Nos. 19 and 30.

The average amount of inbreeding present in the pedigrees of the twenty-eight bulls which raised both milk and butterfat percentage was 7.08 per cent, while for those forty-seven animals which lowered both milk and fat the average amount of inbreeding is 9.65 per cent.

Hunts Studies of Jersey Cattle.—Hunt[1] has studied the Jersey breed from the standpoint of both production and show-yard winnings. Table XXVIII shows the twelve leading sires, as determined by Hunt, for production (number of high-producing daughters), for show-yard winnings (winnings at National Dairy Show, 1910 to 1921), and for combined production and show-yard winnings.

These three different types of investigation yield very similar results so far as indicating the better strains and individuals of the breed is concerned.

Analysis of Ayrshire Class Leaders.—The ten leading animals in each of the seven classes from Jr. two- to five-year-old cows as of June 30, 1924, furnished the basis for this study. Complete four-generation pedigrees were secured and the following table compiled on the same basis as indicated for Jerseys—*i.e.*, appearance of bull or cow as immediate sire or dam of the class leader counts 4 for said bull or cow, appearances in second generation count 3 each, third generation 2 each, and fourth generation 1 each. The following table shows: (1) the rank of the thirty-one bulls scoring 10 or more (plus one bull which scored 8 as the sire of two different class leaders, (2) the number of appearances in the respective generations, (3) the total number of appearances of each bull in these seventy four-generations pedigrees, and (4) the bull's individual scores on the basis outlined above.

There could possibly have been 945 different bulls in these pedigrees. The actual number which occurred was 467. There were 31 bulls which scored 10 or more. These 31 bulls sired 15 of the 70 class leaders, or 0.49 each. Eight other bulls (7 being

[1] HUNT, R. E., Great transmitting sires of the Jersey breed, The Ohio Jersey, Westerville, Ohio, pp. 10–13, 1923.

TABLE XXVIII.—LEADING JERSEY SIRES BASED ON PRODUCTION, WINNINGS, AND BOTH (*From Hunt*)

Production			Show-yard winnings of offspring			Production and winnings		
Rank	Name of sire	No. of over 600-pound daughters	Rank	Name of sire	Score	Rank	Name of sire	Total score
1	Pogis 99th of Hood Farm	72	1	Noble of Oaklands	158	1	Golden Fern's Noble	104
2	Hood Farm Torono	51	2	Flora's Queen's Raleigh	137	2	Oxford Majesty	103
3	Sophie 19th's Tormentor	34	3	Fairy Glen's Raleigh	66	3	Fairy Glen's Raleigh	94
4	Fauvic's Prince	26	4	Golden Fern's Noble	64	4	Oxford You'll Do	93
5	Rosaire's Olga Lad	25	5	Oxford's Majesty	46	5	Fontaine's Chieftain	82
6	The Imported Jap	23	6	Fontaine's Chieftain	45	6	Royal Majesty	82
7	Rinda Lad of S. B	21	7	Sybil's Gamboge	36	7	Queen's Raleigh	73
8	Sayda's Heir 3rd	21	8	Red Flag's Fern Lad	34	8	Sybil's Gamboge	70
9	Spermfield Prince	20	9	Queen's Raleigh	32	9	Royal Majesty of St. Cloud	69
10	Pogis 95th of Hood Farm	19	10	Gamboge Knight	28	10	Raleigh's Fairy Boy	68
11	Sayda's King of Meridale	19	11	Imp. Fern's Oxford Noble	27	11	Gamboge Knight	56
12	Spermfield Owl	19	12	Golden Fern's Grey Prince	23	12	Noble's Jolly Sultan	28

TABLE XXIX.—SCORES OF BULLS IN PEDIGREES OF AYRSHIRE CLASS LEADERS

Name	Rank	Scoring	Number of appearances in pedigrees	Total score
Howie's Dairy King	1	3–5–4–2	14	37
Duke of Wigtown	2	0–4–8–6	18	34
Beuchan Peter Pan	3	4–3–1–1	9	28
Willowmoor Robin Hood	4	3–4–2–0	9	28
Howie's Erin-Go Braugh	6	0–3–5–6	14	25
Finlayston	5	1–3–4–2	10	23
Prince Imperial of Netherhall	7	0–0–6–12	18	24
Lord Douglas I of Maple Grove	8	0–2–3–9	14	21
General Buller of Carsegowan	9	0–0–4–12	16	20
McQuettiston Secretary	10	0–3–4–2	9	19
Gigantic Stunner of Wynholm	11	0–0–5–5	10	15
Sir Colin of Hillhouse	12	0–0–5–5	10	15
Dummondine	13	1–2–2–0	5	14
Moonstone of Drumsuie	14	0–1–4–3	8	14
Commander of Southwick	15	0–2–2–3	7	13
Finlayston Fiscal	16	0–1–3–4	8	13
Morton Mains Queechy	17	1–2–1–1	5	13
Brae Rising Star	18	0–2–3–0	5	12
Babs	19	0–4–0–0	4	12
Major Ayer	20	0–2–3–0	5	12
Nox-em-All	21	0–0–6–0	6	12
Bogwood Prince	22	0–1–2–4	7	11
Bargenoch Durwood Lily	23	0–1–3–2	6	11
Carston Sir David	24	0–3–1–0	4	11
Drumsuie Star of the Morning	25	0–2–1–3	6	11
Garclaugh's Bloomer's Son	26	1–1–2–0	4	11
Lessnessock Doughlas Monarch	27	0–0–5–1	6	11
Rena's Champion	28	1–1–2–0	4	11
Whitehall Envy Me	29	0–0–4–3	7	11
Hobsland Innellan	30	0–2–2–0	4	10
Ringleader of Auchenbrain	31	0–2–1–2	5	10
Nancy's Champion	..	2–0–0–0	2	8

repeats in different classes) sired 16 class leaders, or 2 each. The other 428 bulls occurring in these pedigrees sired 39 class leaders, or 0.09 each.

The following table shows: (1) the rank of the forty-seven cows scoring 7 or more, (2) the number of appearances each cow has in each of the respective generations, (3) the total number of appearances of each of these cows in the seventy four-generation pedigrees, and (4) the scores of the cows on the basis outlined above.

TABLE XXX.—SCORES OF COWS IN PEDIGREES OF AYRSHIRE CLASS LEADERS

Name	Rank	Scoring	Number of appearances in pedigrees	Total score
Brockie of Hillhouse	1	0–3–5–4	12	23
Netheland Brownie 9th	2	0–3–5–2	10	21
Morton Main's Young Bonnie Jean	3	0–4–3–1	8	19
Brownie 5th of Netherhall	4	0–0–4–8	12	16
Carston Evalina	5	3–1–0–0	4	15
Viola Drummond	6	0–1–2–8	11	15
Bess Howie	7	2–2–0–0	4	14
Duchess of Reidston	8	0–0–4–6	10	14
Finlayston Maggie 3rd	9	0–1–3–4	8	13
Yellow Kate of Auchenbrain	10	2–0–0–4	6	12
Carston Daisy 1st	11	0–3–1–0	4	11
Jean of Raithmuir	12	0–0–3–5	8	11
Lily of Barclay	13	1–1–2–0	4	11
Lady Marshall of Carsegowan	14	0–0–3–5	8	11
Southwick Woodbine	15	2–1–0–0	3	11
Young Bonnie Jean 2nd of Wynholm	16	0–0–4–3	7	11
Bessie of Avon	17	0–2–2–0	4	10
Lily of Willowmoor	18	1–2–0–0	3	10
October Lass	19	2–0–1–0	3	10
Castleman's Sweet Marie	20	0–0–3–3	6	9
Castleton Nancy 4th	21	0–3–0–0	3	9
Miss Mot of Foulton	22	0–0–3–3	6	9
Auchenbrain Brown Kate 4th	23	0–0–4–0	4	8
Castleman's Nancy 2nd	24	0–0–4–0	4	8
Caven's Woodbine 4th	25	0–2–1–0	3	8
Douglass Hall Daisy 2nd	26	2–0–0–0	2	8
Daisy Gem	27	1–0–2–0	3	8
Germantown Dora	28	1–0–2–0	3	8
Jean Armour	29	2–0–0–0	2	8
Lura Finlayston	30	2–0–0–0	2	8
Morton Main Emathla	31	0–1–2–1	4	8
Rena Ross	32	1–1–0–1	3	8
Rena Webb	33	0–2–1–0	3	8
Drumsuie Hawthorne	34	0–0–3–1	4	7
Daisy of Carston	35	0–0–3–1	4	7
Garclaugh's Blossom 2nd	36	0–1–1–2	4	7
Keek of Dundee	37	0–0–3–1	4	7
Lily 4th of Fairfield Mains	38	0–1–1–2	4	7
Love 4th of Craighead	39	0–0–2–3	5	7
Nellie Douglas of Glenora	40	0–1–1–2	4	7
Nancy Lee of Willow Lake	41	1–1–0–0	2	7
Old Beauty Last of Auchenbrain	42	0–1–0–4	5	7
Polly Puss	43	0–2–0–1	3	7
Queen Sadie	44	0–0–2–3	5	7
Snowdrop of Robertland	45	0–0–3–1	4	7
White Cordilia	46	0–2–0–1	3	7
White Hill Lily 2nd	47	0–0–2–3	5	7

There might have been 945 different cows in these pedigrees. The actual number appearing was 587. There are, therefore, 25 per cent more different cows than bulls in these pedigrees. This is in accordance with expectation, as bulls are usually selected more carefully and used more extensively and inten-

sively than cows. There were 47 cows that scored 7 or more. These 47 cows were the dams of 23 of the 70 class leaders, or 0.49 each. The other 540 cows appearing in these pedigrees were the dams of the 47 remaining class leaders, or 0.08 each.

The two tables show clearly the animals which have been used most extensively in the producion of the class leaders. Table XXXI is taken from the *Ayrshire Digest* of Apr. 15, 1924. It shows the leading sires as measured by the number of their daughters to be found in the Advanced Registry.

TABLE XXXI.—AYRSHIRE SIRES WITH FIFTEEN OR MORE ADVANCED REGISTRY DAUGHTERS

Sire	Registry number	Number of daughters	Total records	Average milk, pounds	Average fat, pounds
Beuchan Peter Pan	12971, A. R. 104	56	88	11,104	434.41
Finlayston	8882, A. R. 30	55	115	10,801	446.06
Baron's Best of Bargenoch	12858, A. R. 126	43	53	9,998	395.58
Earl's Choice of Spring Hill	8289, A. R. 109	43	70	9,146	383.08
Nox'emall	7312, A. R. 6	35	89	10,057	383.99
White Cloud, of Hickory Island	10377, A. R. 84	32	44	11,387	444.41
Morton Main's Queechy	11537, A. R. 102	27	51	10,096	407,41
Netherton Statesman	16431, A. R. 211	27	36	9,872	395.08
Kate's Good Gift	15426, A. R. 139	27	34	9,638	389.79
Rena's Champion	11816, A. R. 112	26	42	10,991	459.56
Kate's Champion of Penshurst	18782, A. R. 218	24	36	9,198	401.46
Howie's Dairy King	9855, A. R. 72	23	34	11,916	461.66
Willowmoor Robin Hood	11900, A. R. 108	23	41	10,237	445.44
Finlayston Bell	12990, A. R. 163	22	39	10,207	402.15
Moonstone of Drumsuie	8228, A. R. 7	22	31	8,778	357.09
Howie's Predominant	14794, A. R. 201	21	31	11,639	438.31
Leesnessock Douglas Monarch	10020, A. R. 63	20	32	9,747	395.80
Melrose Good Gift	14612, A. R. 137	19	37	10,743	406.77
Holehouse White King	10348, A. R. 76	19	39	10,641	417.31
Willowmoor Robin Hood 18th	15334, A. R. 177	19	27	10,565	419.96
Colonel Ayer	7168, A. R. 14	19	24	8,420	344.87
Netherhall White Robin	13484, A. R. 219	18	18	11,275	486.29
Yellow Kate's Exchange of Penshurst	16596, A. R. 234	18	19	10,026	446.29
Garclaugh's Bloomer's Son	104081, A. R. 140	17	39	11,802	481.39
Bargenoch Bonnie Scotland	11974, A. R. 109	17	19	9,216	371.15
Stonehouse Pansy Boy	15677, A. R. 187	16	21	8,927	360.31
Willowmoor Sentinel	11779, A. R. 130	15	26	10,757	432.61
Foulton Spicy John	12584, A. R. 162	15	18	9,474	352.36
Moonshine of Barclay	10261, A. R. 92	15	22	9,027	365.78
Barcheskie Copestone	10034, A. R. 69	15	19	8,905	348.52
Howie's Fizzaway	9370, A. R. 71	15	16	7,867	315.43

It will be noticed that twelve of the sires appearing in this list (Nos. 1, 2, 5, 6, 7, 10, 12, 13, 15, 17, 19, and 24) also appeared in the previous list of high-scoring animals as found in the pedigrees of the seventy class leaders. The development of families has not

progressed so far in the Ayrshire breed as in some others. There are even today no recognized families in the breed and this need should be met. Desirable animals are as plentiful in this breed as in others and there is no breed which excells it from the standpoint of type. The inbreeding figures which follow show the class leaders of Ayrshires to be but little inbred. The segregation and the intensification of blood (families) in Ayrshires remain to be done. Intensification of blood carrying factors for high milk and butterfat production should mean greater production of milk and fat.

Inbreeding and Relationship Values in Ayrshire Class Leaders. The pedigrees were evaluated for their Z and K values, with the following results.

TABLE XXXII.—INBREEDING AND RELATIONSHIP VALUES IN AYRSHIRE CLASS LEADERS.

Number	Name	Registry number	Z_1	Z_2	Z_3	Z_{t_3}	K_1	K_2	K_3
1	Garchaugh May Mischief	27944	0	0	6.25	3.0	0	0	12.5
3	Auchenbrain Brown Kate 4th	27943	0	12.5	12.5	11.3	0	25	25
4	Nancy Whitehall	47810	0	0	18.75	8.8	0	0	0
6	Auchenbrain Yellow Kate 3rd	36910	0	12.5	12.5	11.3	0	0	0
7	Harperland Spicy Lass	40652	0	12.5	12.5	11.3	0	25	25
8	Geuanton Dore 2nd	23853	0	0	6.25	3.0	0	0	0
12	Agawam Bess Howie	43781	25	25	25	35.3	50	50	50
14	Henderson Betty 3rd	45526	0	0	6.25	3.0	0	0	0
16	Willowmoor Miss Carston	42924	0	0	6.25	3.0	0	0	0
23	Nancy Whitehall	47811	0	0	18.75	8.8	0	0	0
24	Willowmoor Vesta 4th	34150	0	12.5	12.5	11.3	0	0	0
29	Victor's Beauty Lass	44025	0	0	6.25	3.0	0	0	0
32	Orchard Home Betty	69877	0	12.5	12.5	11.3	0	0	0
33	Willowmoor Miss Carston	42924	0	0	6.25	3.0	0	0	0
34	Agawam Bess Howie	43781	25	25	25	35.3	50	50	50
35	Sarah Lee of Bonnie Doone	51554	25	25	25	35.3	50	50	50
36	Boggie of Eastside	60405	0	0	6.25	3.0	0	0	0
38	Hattie of Willow Lake	55344	25	25	25	35.3	50	50	50
39	The Abbess of Torr	27964	0	0	6.25	3.0	0	0	0
40	Lotus Lady Fox	34751	0	0	6.25	3.0	0	0	0
41	Willowmoor Marion	51373	25	25	25	35.3	50	50	50
42	Letos Rosette	48858	0	0	6.25	3.0	0	0	12.5
47	Alta Crest Destiny	63436	0	0	6.25	3.0	0	0	0
50	Nether Craig Rosebud	70563	0	0	6.25	3.0	0	0	0
52	Bonnie Mary Douglas	59431	0	0	6.25	3.0	0	0	0
53	Willowmoor Lily 9th	46060	0	12.5	18.75	14.7	0	0	0
55	Willowmoor Woodbine B	34152	0	12.5	12.5	11.3	0	0	0
56	Barclay's Sweet Pea 3rd	59233	25	25	25	35.3	50	50	50
59	Hilltop Old Gypsy	62718	0	0	6.25	3.0	0	0	0
60	Henderson's Lassie 4th	49498	0	12.5	18.75	14.7	0	25	37.5
62	Willowmoor Etta 3rd	35833	0	12.5	18.75	14.7	0	0	12.5
64	B. M.'s Bangora Melrose	60018	0	0	12.5	5.9	0	0	12.5
67	Willowmoor Miss Carston	42924	0	0	6.25	3.0	0	0	0
68	Willowmoor Woodbine 4th	46099	0	0	6.25	3.0	0	0	0
69	Oregon Panetta J	59203	0	12.5	12.5	11.3	0	25	25
70	Willowmoor Thrush	42925	0	0	6.25	3.0	0	0	0

The table shows that thirty-six, or 51 per cent, of these class leaders are inbred to some extent up to and including the fourth generation. Five of these leaders are inbred in the Z_1 or grandparental generation. The average amount of inbreeding shown by the seventy animals is 5.68 per cent of the greatest amount possible. Not one of the class leaders is inbred more than 25 per cent in the Z_3 or fourth generation back, and the low relationship or K values also indicate that there has been very little intensification of blood lines among these class leaders. Only 38 per cent of the animals that are inbred show K values, indicating that in most cases the intensification of the blood of certain animals was to be found on only one side of the pedigree.

The Ayrshire breed is native to Scotland. It would seem that it's breeders had been influenced to some extent by the breeders of beef cattle, for which the British Isles are particularly noted. At any rate, the Ayrshire usually carries more flesh than do the other so-called dairy breeds. It should be evident that if a cow is selected for her ability to convert her feed into meat she will not convert it into milk. The Ayrshires as a breed are very uniform and "typey." They have evidently been selected with the major emphasis on type. The class leaders of this breed rank lowest as regards average butter-fat produced and also lowest in milk when converted to a 4 per cent basis. This again evidences that if one desires both type and production one must select for both. In other words, selection can be depended upon to give what is selected, for nothing else is guaranteed to follow.

Analysis of Holstein-Friesian Class Leaders.—The ten class leaders in each of the classes of Holsteins from junior two-year-olds to mature cows inclusive as of Dec. 1, 1924, furnished the materials for this study. Four-generation pedigrees of these animals were tabulated and the animals scored as previously indicated in Jerseys and Ayrshires, an appearance in the first generation counting 4, in the second generation 3, and so on. The following tables show the standing of the bulls and cows which scored over 10 and over 7 respectively. In this breed there were thirty-four bulls that scored 10 or more. Two bulls which scored 8 as the immediate sires of two class leaders have been included. The table shows: (1) the rank of the bulls, (2) the number of appearances in each of the generations, (3) the total number of appearances, and (4) the total score of each bull.

TABLE XXXIII.—HIGH-SCORING BULLS IN PEDIGREES OF HOLSTEIN-FRIESIAN CLASS LEADERS

Name	Rank	Scoring	Number of appearances	Total
King Segis	1	0–1–13–14	28	43
Sir Pietertje Ormsby Mercedes	2	3–9–0–1	13	40
King of the Pontiacs	3	0–1–8–9	18	28
Jack Mercedes	4	0–3–9–0	12	27
Pontiac Korndyke	5	0–0–2–22	24	26
Hengerveld De Kol	6	0–0–8–9	17	25
King Segis Pontiac	7	0–5–3–2	10	23
Sir Ormsby Hengerveld De Kol	8	0–1–4–12	17	23
Sir Johanna Canary De Kol	9	0–3–6–1	10	22
Sir Pietertje Ormsby Mercedes 37	10	5–0–0–0	5	20
King Segis Pontiac Count	12	4–1–0–0	5	19
De Kol 2nd Butter Boy 3rd	11	0–2–4–4	10	18
Sir Veeman Hengerveld	13	0–4–0–5	9	17
King Fayne Segis	14	0–2–4–2	8	16
Sir Veeman Korndyke Pontiac	15	4–0–0–0	4	16
Friend Hengerveld De Kol Butter Boy	16	1–2–1–3	7	15
Mercedes Mechthilde Pietertje	17	0–0–3–9	12	15
Mercedes Julips Pietertje Paul	18	0–0–1–13	14	15
Canary Mercedes Paul	19	0–0–3–8	11	14
Wisconsin Bess Chief	20	0–0–3–8	11	14
Johanna Rues 3rd Lad	21	0–1–1–7	9	12
King Hengerveld Aaggie Fayne	22	2–0–2–0	4	12
Manor De Kol	23	0–0–2–8	10	12
Forbes Tritomia Mutual De Kol	24	0–1–2–4	7	11
Homestead Jr. De Kol	25	0–0–2–7	9	11
Paul De Kol	26	0–0–1–9	10	11
Sarcastic Lad	27	0–1–1–6	8	11
Aaggie Cornucopia Johanna Lad	28	0–0–3–4	7	10
Beauty Pietertje Prince	29	0–2–1–2	5	10
Colantha Johanna Champion	30	0–1–2–3	6	10
De Kol 2nd Butter Boy	31	0–0–0–10	10	10
King Segis 10	32	1–2–0–0	3	10
Sir Korndyke Pontiac Artis	33	0–0–5–0	5	10
Spring Farm Pontiac Cornucopia	34	0–2–2–0	4	10
Dutchland Creamelle Colantha Lad	..	2–0–0–0	2	8
Segis Walker Matador	..	2–0–0–0	2	8

There could have been 1,020 different bulls in these 68 pedigrees (2 *repeats*). There were actually found only 521, or about 50 per cent of the number possible. The 34 bulls scoring 10 or more (plus the 2 which scored 8) are the sires of 24 of the 70 class leaders, or they have 0.66 of a class leader each to their credit. The other 485 bulls sired the remaining 45 class leaders, or 0.09 each. It is interesting to note that 32 per cent of all these bulls include the name De Kol in their name.

The following are the more important families in the Holstein Breed: De Kol, Pietertje, Netherland, Pauline Paul, Colantha, Johanna, Clothilde, Aaggie, Korndyke, Segis, Ormsby, Homestead. There are other families in the breed, also many subfamilies and combinations. There has been much intercrossing of families in this breed and comparatively little breeding that has been kept within a family.

Table XXXIV shows a more or less arbitrary grouping of the high-scoring bulls into families.

TABLE XXXIV.—HIGH-SCORING HOLSTEIN BULLS IN FAMILY GROUPS

FAMILY	BULL'S NUMBERS
De Kol	6, 12, 13, 15, 16, 23, 26, 31, 33
Segis	1, 7, 11, 14, 18, 22, 32
Ormsby	2, 4, 8, 10, 17
Korndyke	3, 5, 12, 34
Homestead	20, 22, 25, 30
Sarcastic Lad	21, 22, 27, 28
Bess Burke	9, 10
Colantha	30

Table XXXV shows the high-scoring cows occurring in the pedigrees of the seventy class leaders of the breed.

TABLE XXXV.—HIGH-SCORING COWS IN HOLSTEIN-FRIESIAN CLASS LEADERS

Name	Rank	Scoring	Number of appearances	Total
Pietertje Maid Ormsby	1	0–3–10–0	13	29
Spring Brook Bess Burke 2	2	1–6–0–0	7	22
Pietertje of Groun 3	3	0–0–3–12	15	18
A and G Inka McKinley	4	0–0–1–13	14	15
Spring Brook Bess Burke	5	0–1–6–0	7	15
Sadie Mechthilde	6	0–0–3–9	12	15
K. P. Lilith Clothilde	7	0–4–1–0	5	14
Pontiac Clothilde De Kol 2	8	0–0–5–4	9	14
Beatrice Korndyke Pontiac Vernon	9	0–4–0–0	4	12
Easle Johanna De Kol	10	0–0–3–6	9	12
De Kol 2	11	0–0–2–7	9	11
Pontiac Lunde Hengerveld	12	0–0–1–9	10	11
Lilith Clothilde Boon	13	0–0–4–1	5	9
Spring Brook Burke	14	0–0–1–7	8	9
Aaggie Cornie Johanna	15	2–0–0–0	2	8
Bloomingdale Hengerveld Aaggie	16	0–2–0–2	4	8
Daisy Aaggie Ormsby	17	2–0–0–0	2	8
De Kol Jewel Pontiac	18	2–0–0–0	2	8
Friend Hengerveld Mutual	19	1–0–2–0	3	8
Grace Fayne 2nd Homestead	20	0–0–2–4	6	8
Jessie Veeman Hengerveld	21	0–0–4–0	4	8
Magadora	22	0–0–0–8	8	8
Pontiac Clothilde De Kol	23	0–0–0–8	8	8
Friend Hengerveld De Kol	24	0–1–2–1	4	8
Johanna Vernon De Kol	25	0–1–2–0	3	7
Lady Netherland De Kol Wayne	26	1–1–0–0	2	7
Mercedes Julip Pietertje	27	0–0–1–5	6	7

Of the possible 1,020 different cows that could have occurred in these pedigrees, 722 did actually occur. There are, therefore, 38 per cent more different cows than bulls in these pedigrees—in other words, bulls are used more intensively than are cows, as would be expected.

The 27 cows that score 7 or more are the dams of 9 of the class leaders, or 0.33 each, while the other 695 are the dams of the remaining 61 class leaders, or 0.09 each.

Inbreeding and Relationship Values in Holstein Class Leaders. The following table shows the inbreeding and relationship values for those of the class leaders which are at all inbred up to and including the fourth generation.

TABLE XXXVI.—INBREEDING AND RELATIONSHIP VALUES IN HOLSTEIN-FRIESIAN CLASS LEADERS

Number	Name	Registry number	Z_1	Z_2	Z_3	Z_{l_3}	K_1	K_2	K_3
2	May Walker Ollie Homestead	300043	0	0	6.25	3.0	0	0	0
3	Hollywood Lilth Palmyra Abbekerk	400491	0	12.5	12.5	11.3	0	0	0
6	Finderne Pride Johanna Rue	121083	0	0	12.5	5.9	0	0	12.5
7	Segis Pietertje Prospect	221846	0	0	6.25	3.0	0	0	0
8	Adirondac Wietske Dairy Maid	204072	0	12.5	12.5	11.3	0	0	0
10	Poplar Jewels De Kol	198322	0	0	12.5	5.9	0	0	12.5
11	Grahamholm Colantha Pauline Segis	405465	0	0	6.25	3.0	0	0	0
15	Helm Veeman Woodcrest	486877	0	0	6.25	3.0	0	0	0
16	S. V. K. P. Melba of Sunnyside	466270	0	0	12.50	11.3	0	0	0
17	Tillamook Daisy Butter King De Kol	407854	0	0	6.25	3.0	0	0	0
20	Geertje Queen De Kol Posch 2nd	311283	0	0	6.25	3.0	0	0	12.5
24	California Pietertje Bloom Mead	450151	0	0	6.25	3.0	0	0	0
25	Milanhurst America De Kol	143441	0	0	6.25	3.0	0	0	12.5
27	Daisy Grace De Kol	98228	0	0	6.25	3.0	0	0	0
29	Grahamholm Winana Segis Colantha	445999	0	0	6.25	3.0	0	0	0
30	Bess Oak	346177	0	12.5	12.5	11.3	0	0	0
31	Wisconsin Pride 2nd	427126	0	0	6.25	3.0	0	0	0
33	Queen Olathe Bess Ormsby	587844	0	0	6.25	3.0	0	0	12.5
34	Daisy Aaggie Ormsby 3rd	571569	0	0	12.5	5.9	0	0	25
36	M'Cormick Nina Burke Henger-veld	488473	0	0	6.25	3.0	0	0	12.5
37	Jewel Pontiac Segis	229261	0	0	6.25	3.0	0	0	0
40	Lindale Betta Walker	491469	0	0	6.25	3.0	0	0	0
42	Tazewell Cornycopia Piebe	738989	0	0	12.5	5.9	0	0	12.5
43	Fairmont Colantha Prilly	565010	0	0	12.5	5.9	0	0	12.5
46	Anoakia Pontiac Beets 2nd	446754	0	0	12.5	5.9	0	0	25
49	Miss Valley Mead De Kol Walker	250936	0	0	6.25	3.0	0	0	0
50	Beauty Girl Pontiac Segis	229260	0	0	6.25	3.0	0	0	0
51	Queen Bessie Pietertje Ormsby	648084	0	0	6.25	3.0	0	0	0
52	Pontiac Irene	351698	0	0	6.25	3.0	0	0	0
55	Bessie Veeman Alcartra Prilly	422620	0	0	6.25	3.0	0	0	12.5
57	Beauty Beets Walker Segis	290163	0	0	6.25	3.0	0	0	0
61	Finderne Mutual Fayne	183215	0	12.5	18.75	14.7	0	25	37.5
64	Daisy Aaggie Ormsby 3rd	571569	0	0	12.5	5.9	0	0	25
65	Mankato Floa Ormsby Mercedes	516764	0	0	6.25	3.0	0	0	0
66	Bell Farm Hattie	557118	0	0	6.25	3.0	0	0	12.5
67	Miss Aaggie Acme Burke	402643	0	12.5	12.5	11.3	0	0	0
68	Walcowes Ollie Mooie	339500	0	0	6.25	3.0	0	0	12.5
69	Jewel Pontiac Segis	229261	0	0	6.25	3.0	0	0	0
70	Rosamines Dora Netherland	477596	25	37.5	43.75	50.0	50	75	75

There are thirty-eight of these class leaders, or 54 per cent, which show inbreeding to some extent. As is evident from the table, most of these animals are inbred to only a very slight extent. Only one is the result of a mating as close as half brother and sister, giving a value in Z_1. Only six of these show a value in Z_2. Most of the inbreeding occurred in the fourth generation

back, or at least was first evidenced there in the pedigree. If, for instance, one of the grandsires of the class leaders was mated to his own granddaughter to produce one of the immediate parents of the class leaders there would result a value of 6.25 in the Z_3 or fourth generation. The total amount of inbreeding compared to the amount possible (continued brother-and-sister mating) is very small, being only 3.27 per cent of that possible. This breed has been selected primarily for milk production. As milk production is a matter of energy production, it is inevitable that under such a system of selection fat percentage must decrease. It is also true that individuality or type has not received the attention it merits. More intensive breeding would no doubt have increased production, but at the same time it would have had an excellent opportunity in this breed to intensify poor conformation. Steps are being taken by Holstein breeders to overcome the matter of low fat test and lack of uniformity.

The Prescotts' Study of Holstein Foundations.—In Holstein-Friesian Foundations by Prescott and Prescott there appears a table showing the number of times important foundation animals appear in the ancestry of each of the first seventy-five 1,000-pound fat producers. The foundation animals and number of appearances are as follows:

TABLE XXXVII.—APPEARANCE OF FOUNDATION ANIMALS IN PEDIGREES OF 1,000-POUND FAT PRODUCERS (*After Prescott and Prescott*)

FOUNDATION ANIMALS	APPEARANCES	FOUNDATION ANIMALS	APPEARANCES
De Kol 2nd	827	Tritomia	78
Pauline Paul	309	Aaggie	367
Netherland Hengerveld	131	Echo	65
Pietertje 2nd	392	Queen of Wayne	151
Belle Korndyke	36	Mooie	475
Clothilde	322	Jacoba Hartog	269
Empress	458	Inka	133
Johanna	201	Netherland Prince	1,650
Mechthilde	359	Milla's Pietertje Netherland	278
Mercedes	136	Paul De Kol	273
Colantha	81	Billy Boelyn	871
Helena Burke	32	Sir Henry of Maplewood	343
Jewel	57		

In discussing the system of breeding used in producing these seventy-five 1,000-pound fat producers the authors point out

that only one cow, Aaggie Acme of Riverside 2nd, is the result of mating a half brother and sister, this being the nearest approach to inbreeding to be found in these pedigrees.

Adirondac Wietske Dairy Maid, the first and thus far the only cow of any breed to make three records each above 1,000 pounds of butterfat or three above 30,000 pounds of milk, was by the inbred sire, Gem Paul Johanna, whose sire and dam were both by Johanna Aaggie 2nd's Lad, one of the outstanding sons of Sarcastic Lad. Reference to this pedigree, traced back a number of generations, reveals more inbreeding on

FIG. 76.—Adirondac Wietske Dairy Maid, a Holstein cow with 4 records each above 30,000 lb. of milk and 1,000 lb. of fat.

the dam's side, the granddam of the dam, Woodland Dairy Maid, being produced by mating a son and a daughter of Sir Duke. It is interesting to note, in this connection, that line breeding, likewise, contributed to producing the sire of the dam of Adirondac Wietske Dairy Maid, he being from a daughter of Woodland Belle and his sire being from another daughter of the same cow . . .

The pedigree of Adirondac Wietske Dairy Maid is appended on page 244.

It is evident, from a study of the pedigrees, however, that line breeding has been much more generally practiced in the pedigrees of these Dairy Queens than has been inbreeding. The names of De Kol 2nd,

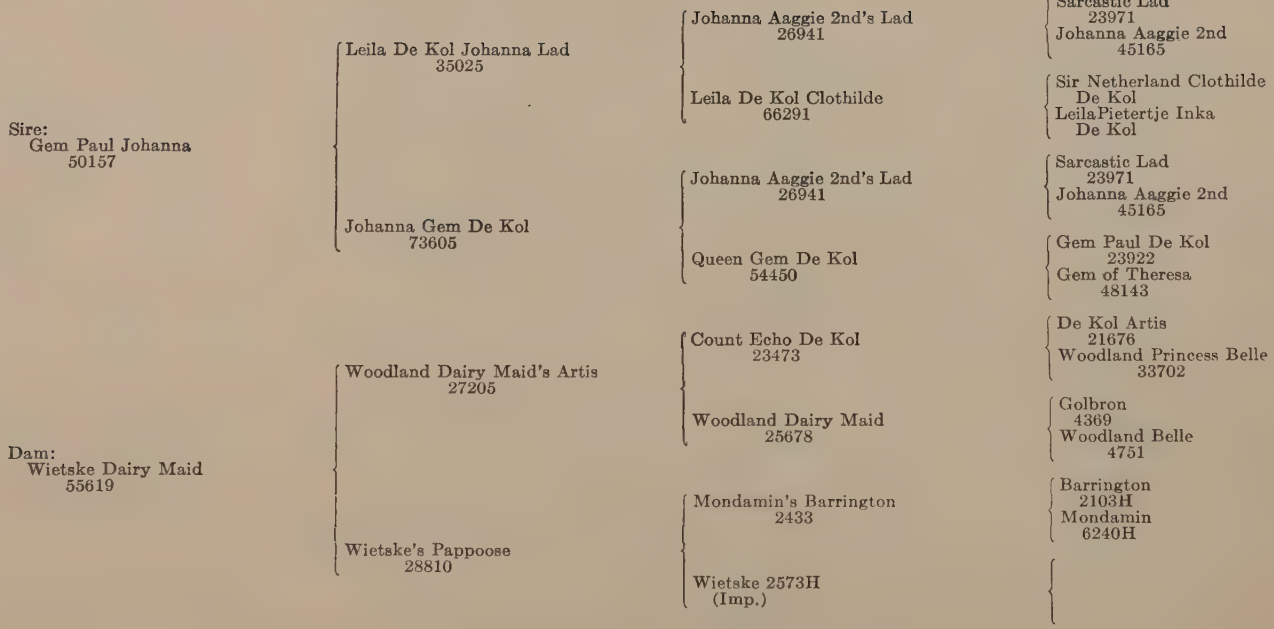


FIG. 77.—Pedigree of Adirondac Wietske Dairy Maid.

Pauline Paul, Milla's Pietertje Netherland, and others are constantly recurring time after time in a large proportion of the pedigrees. Thus, we find that Segis Pietertje Prospect traces no less than fifteen times to Milla's Pietertje Netherland, with two additional crosses of Pietertje 2nd, ten crosses of De Kol 2nd, eighteen crosses of Clothilde and Jacoba Hartog, twenty crosses of Mooie, fourteen of Billy Boelyn, and fifty-four of Netherland Prince. De Kol Plus Segis Dixie traces fourteen times to De Kol 2nd through four of her sons, five times to Netherland Hengerveld through two of her sons, eight times to Milla's Pietertje Netherland, seven times to Aaggie Leila's Prince, who sired Netherland Hengerveld and Inka Princess, and no less than thirty-one times to Netherland Prince through four sons and one daughter. Champion Dora Korndyke, formerly the leader in the Holstein-Friesian breed for two consecutive years' production traces to six of the eight sons of De Kol 2nd, going to one of them four times, and twice to two others. Both grandsires of Tilly Alcartra are sons of De Kol Burke, while Spring Brook Bess Burke, foundation of one of the great later-day families, carries 25 per cent of the blood of Pearl of the Dairy, her great granddam, through both a son and daughter. Similar instances could be multiplied almost indefinitely in these pedigrees . . .

Without citing more of the many examples, we believe that a study of the pedigrees of these greatest producers of the breed will show a case for line breeding that is very clearly cut. Experience of breeders has shown, however, that there are certain dangers of excessive intensification of the blood of one animal, particularly when that animal has any pronounced weakness or fault, inbreeding especially having a tendency to exphasize such faults, rather than to correct them. The best results from either inbreeding or line breeding have been obtained when the animals intensified have many good characteristics and no very bad ones. This type of breeding calls for the highest skill on the part of the breeder, as to both matings and selection.[1]

Maine Experiment Station Studies of Holstein Cattle.—Professor J. W. Gowen of Maine has analyzed the Advanced Registry records occurring in Vols. 13 to 32 of the Holstein-Friesian Association in order to ascertain the transmitting qualities of Holstein-Friesian sires for milk yield, butter-fat percentage, and butter-fat. The attempt was made to include all bulls with two or more daughters having year records if their dams also had year records.

One hundred and eleven bulls were found which met the above specifications. Of these seventy-one affected a net butter-fat increase of daughters over dams and forty a decrease.

[1] PRESCOTT, M. S. and W. A., Holstein-Friesian Foundations, p. 12, Holstein-Friesian World, 1923.

Tables XXXVIII and XXXIX are taken from Gowen:[1]

TABLE XXXVIII.—HOLSTEIN-FRIESIAN SIRES WHICH INCREASED THE MILK YIELD AND BUTTERFAT PERCENTAGE OF THEIR DAUGHTERS OVER THAT OF THEIR DAMS (*From Gowen*)

Number	Name of bull	Register number	Number of pairs	Net increase		
				In milk, pounds	In fat, per cent	In net fat, pounds
1	Johan Woodcrest Lad	52145	3	5,140.0	0.413	239.47
2	Emblagaard Tritomia Homestead	62924	5	6,716.4	0.024	227.46
3	Alcartra Polkadot Corrector	30624	2	3,420.5	0.405	182.21
4	Sir Korndyke Hengerveld De Kol	41266	6	3,665.7	0.259	173.00
5	King Pontiac Champion	53418	14	4,862.1	0.004	170.40
6	Korndyke Netherland Wayne De Kol	47306	2	2,285.5	0.360	150.10
7	Homestead Girl De Kol Sarcastic Lad	32558	4	1,995.5	0.338	143.18
8	King Pietertje Cloverdale	69686	3	1,817.0	0.354	140.28
9	Greenwood Johanna Lyons	62049	2	2,057.0	0.340	137.76
10	Prince Pietertje Beryl	46977	2	1,500.0	0.420	137.06
11	Woodcrest Tehee	74219	10	3,357.6	0.062	121.63
12	King Segis Hengerveld Vale	60344	5	3,176.4	0.044	117.18
13	King Mead of Riverside	50290	6	871.5	0.304	98.08
14	Pietertje Hengerveld Sir Korndyke	60966	5	2,040.8	0.116	94.16
15	King of the Pontiacs	39037	3	1,789.7	0.113	91.84
16	Sir Korndyke Hengerveld Canary	53825	2	2,643.0	0.015	89.43
17	Canary Paul	48328	3	990.0	0.306	85.58
18	Sir Johanna Piebe	53257	10	2,338.4	0.009	82.85
19	Gem Pietertje Paul De Kol 3rd	44658	5	900.8	0.290	81.37
20	Downing Johanna Burke De Kol	84472	2	1,196.0	0.200	73.60
21	Aaggie Cornucopia Pauline Count 13th	44293	4	448.0	0.210	54.47
21	Hartog Paul Burke	49910	3	520.0	0.207	45.63
23	Small Hopes Korndyke De Kol	32260	2	979.5	0.070	43.62
24	Sir Winana Beet's Segis	52927	2	79.0	0.220	37.81
25	Johanna Rue 2nd's Paul De Kol	21724	4	975.2	0.005	32.37
26	Knight Errant	39566	2	89.5	0.145	30.07
27	Sarcastic Lad	23971	5	280.4	0.012	10.41

It is interesting to note that two of the bulls occurring in this list of bulls which raised both milk yield and butterfat percentage of daughters over their dams also occur in the list of bulls which are among the thirty-four high scorers when subjected to the other type of investigation. A comparison further showed that six of the high-scoring bulls also were to be found in Gowen's more complete list (111 bulls), five of them raising milk production of daughters over dams and 1 lowering it, though this last record is based on two daughters coming from cows with very good milk

[1] GOWEN, J. W. and COVELL, M. R., Studies in milk secretion, *Maien Agr. Exp. Sta. Bull.* 301, pp. 290–291, 1921.

yields (classifying as A and B), the bull getting two B daughters. All six of these bulls raise butter-fat percentage of daughters over dams. None of the high-scoring bulls are found among the bulls which lower both milk and butter-fat production of daughters as compared with dams.

TABLE XXXIX.—HOLSTEIN-FRIESIAN SIRES WHICH DECREASED THE MILK YIELD AND BUTTERFAT PERCENTAGE OF THEIR DAUGHTERS AS COMPARED WITH THAT OF THEIR DAMS (*From Gowen*)

Number	Name of bull	Register number	Number of pairs	Net decrease		
				In milk, pounds	In fat, per cent	In net fat, pounds
1	Ladoga King Veeman De Kol	43496	2	3,567.5	0.460	230.55
2	Lakeside Model Alban	71013	2	3,209.5	0.285	159.48
3	Alma Prince Jewel	32731	2	3,908.5	0.110	152.81
4	Pietertje 22nd's Son	58314	2	3,467.5	0.135	150.04
5	Sir Johanna Aaggie Posch 4th	72013	2	2,022.0	0.335	149.39
6	Sir Korndyke Hengerveld De Kol 36th	85968	3	2,975.3	0.087	122.93
7	Pabst Pontiac Champion	105106	2	861.0	0.425	114.73
8	Oak De Kol 2nd Homestead Fobes	65750	2	3,246.0	0.060	114.30
9	Mutual Piebe De Kol	44554	4	251.3	0.427	87.82
10	Sir College Cornucopia	59755	2	1,904.5	0.155	86.64
11	King Pontiac Ruby Burke	58041	2	1,728.0	0.125	82.69
12	Johanna De Colantha Champion	60574	13	1,081.9	0.189	74.55
13	Maplecrest Butter Boy De Kol	94156	2	809.5	0.225	73.48
14	Missouri Chief Josephine Lad	70857	3	27.3	0.304	61.09
15	Sir Johanna Bonheur Fayne	45671	6	383.3	0.220	56.79
16	Earl Korndyke De Kol	24954	2	1,306.0	0.080	56.35
17	Sir Concordia Korndyke	75012	2	770.0	0.095	50.59
18	Colantha Johanna Lad	32481	2	279.0	0.140	45.85
19	King Hengerveld Pondyke	47843	6	779.5	0.073	39.09
20	Sir Musser Clyde De Kol	40368	2	674.5	0.080	38.01
21	Aralia De Kol Pontiac Segis	112077	2	369.0	0.030	19.40

Inbreeding and relationship studies on the bulls represented in Tables XXXVIII and XXXIX show a very slight amount of inbreeding in both groups and an approximately similar amount in each group, 2.5 per cent of greatest possible inbreeding up to the fifth generation for the increase group and 3.8 per cent for the decrease group.

One further question remains, namely, Do the animals occurring in the pedigrees of the sires which increase production of daughters over dams also occur as frequently or nearly so in the pedigrees of those sires which lower production? Gowen has worked out these relationships in both groups and expressed them in Table XL.

TABLE XL.—CORRELATION COEFFICIENTS FOR THE FREQUENCY OF APPEARANCE OF BULLS AND COWS WITHIN THE PEDIGREES OF THE SIRES OF THE THREE FOLLOWING GROUPS: (1) SIRES WHOSE DAUGHTERS WERE BETTER THAN THEIR DAMS IN MILK YIELD AND BUTTERFAT PERCENTAGE (INCREASE GROUP), (2) S ES WHOSE DAUGHTERS WERE LOWER THAN THEIR DAMS IN MILK YIELD AND BUTTERFAT PERCENTAGE (DECREASE GROUP), (3) SIRES OF RANDOM SAMPLE GROUP WITHOUT ADVANCED REGISTRY OFFSPRING (*From Gowen*)

Characters correlated	Males	Females
Increase group and decrease group	0.73 ± 0.02	0.70 ± 0.03
Increase group and random-sample group	0.52 ± 0.04	0.49 ± 0.04
Decrease group and random-sample group	0.37 ± 0.04	0.34 ± 0.05

It is quite generally and correctly recognized that in all of the breeds of livestock there are certain families, strains, and individuals that are more prepotent for desirable characteristics than the average or general mass of the particular breed in question. It should also be just as evident that the mere inclusion of even a goodly number of animals of good repute in any pedigree is no guarantee of excellence in the individual in question. There are several ways of explaining this state of affairs, *e.g.*, an unfortunate blending of blood lines or unfavorable "nick;" preponderance of "bad blood;" one or two very inferior animals close up in the pedigree; the fact that even the best animals are liable to leave inferior offspring from certain matings; the way in which the individual was developed; the fact that the animal of "good repute" may have won its reputation through one or two outstanding offspring in spite of having begotten a great many more of the inferior kind. The point to be made and stressed is that the performance test must always be applied. In selecting a good individual one may get very desirable somataplasm capable of large, efficient production. Both the individual and the pedigree will indicate the sort of germplasm which should be present in such an individual, but the only way to ascertain exactly just the kind of germplasm present is to see it manifested as somatoplasm in offspring.

Analysis of Guernsey Class Leaders.—The ten leading cows in the several classes of the Advanced register as they appeared on Jan. 1, 1925, furnished the material for this study. Four-

generation pedigrees were tabulated and the individuals scored as they were in the other three breeds of dairy cattle already discussed, an appearance in the first generation counting 4, in the second generation 3, and so on.

The following table shows: (1) the bulls which scored 10 or more (also four bulls which scored 8 as the sires of two different class leaders), (2) the number of appearances in each of the four generations, (3) the total number of appearances of each bull, and (4) the total score of each.

TABLE XLI.—HIGH-SCORING BULLS IN THE PEDIGREES OF THE GUERNSEY CLASS LEADERS

Name	Rank	Scoring	Total appearances	Total score
King of the May	1	3–4–16–17	40	73
May Rose King	2	0–3–8–29	40	54
Dolly Dimple May King of Langwater	3	1–5–9–2	17	39
Glenwood Boy of Haddon	4	2–0–4–16	22	32
Governor of the Chene	5	0–3–5–7	15	26
Yeoman	6	1–0–5–12	18	26
Golden Secret	7	0–5–3–4	12	25
Ne Plus Ultra	8	2–4–0–2	8	22
May Day	9	0–0–3–15	18	21
Loyal of the Hunguets	10	0–0–2–10	12	14
Itchen Jewel	11	0–0–1–12	13	14
Masher Sequel	12	0–0–2–9	11	13
Langwater Demonstrator	13	2–1–1–0	4	13
France's Masher II	14	0–0–3–7	10	13
Columbia	15	0–0–5–3	8	13
Golden Secret of Lilyvale	16	2–1–1–0	4	13
Penwyn	17	0–2–0–6	8	12
Jethro Bass	18	0–0–4–4	8	12
Compact	19	0–0–3–6	9	12
Pat of Haddon	20	0–2–0–5	7	11
Lord Mar	21	0–2–2–1	5	11
Jethro's May King of Linda Vista	22	0–1–4–0	5	11
Stranford Glenwood of Pinehurst	23	0–0–5–0	5	10
Langwater Holiston	24	1–2–0–0	3	10
Governor I of the Chene	A	2–0–0–0	2	8
Langwater Stars and Stripes	B	2–0–0–0	2	8
Cotte's Royal Laddie	C	2–0–0–0	2	8
Bellfounder	D	2–0–0–0	2	8

There were 1,005 different bulls which might have been found in these 67 different pedigrees. Actually 524 were found. Twenty-four bulls scored 10 or more and 4 scored 8 as the sires of two different class leaders. These 28 bulls are the sires of 22 class leaders, or 0.78 each. The other 496 bulls are the sires of the remaining 48 class leaders, or 0.09 each.

The following are the commonly accepted leading families in Guernseys: May Rose, Masher, Governor of the Chene, Glenwood, Sheet Anchor, Dolly Bloom, France, Matera, Tricksey, and Yeksa.

The tremendous importance of the May Rose family is indicated by the following table, which groups the bulls occurring in the previous table of high scorers into their respective families.

TABLE XLII.—HIGH-SCORING GUERNSEY BULLS IN FAMILY GROUPS

FAMILY	BULLS' NUMBERS
May Rose	1, 2, 3, 6, 7, 8, 9, 10, 11, 13, 15, 16, 18, 22, 24, B, C
Masher	12, 14, 21, D
Governor of Chene	5, 19, A
Glenwood	4, 20, 23

It will be good training for the student to arrange such material as that given above into a geneology table, *e.g.*, starting with May Rose II, listing her sons and daughters and other offspring. The amount of indentation can show degree of remoteness from May Rose II.

In a list of Advanced Registry sires with more than twenty Advanced Registry progeny as they appeared Dec. 31, 1923, are to be found sixteen of the twenty-eight bulls comprising the foregoing table. Some of the bulls in this table are old bulls which lived and died before the days of the Advanced Register, while others are so young that they have not yet had a fair chance to get into the list of the twenty or more Advanced Registry progeny.

Table XLIII shows the comparable relationships in the cows occurring in the pedigrees of the seventy class leaders of the Guernsey breed.

Different cows to the number of 1,005 might have appeared in these pedigrees; 688 actually did appear. The different cows are, therefore, 31 per cent more numerous than the bulls in these Guernsey pedigrees, indicating again that the bulls are used more intensively. These 20 high-scoring cows are the dams of 11 of

TABLE XLIII.—HIGH-SCORING COWS IN THE PEDIGREES OF THE GUERNSEY CLASS LEADERS

	Rank	Scoring	Total appearances	Total score
Itchen Daisy 3rd	1	0–4–9–19	32	49
Dolly Dimple	2	0–3–5–9	17	28
Dolly Bloom	3	1–0–6–9	16	25
Daisy Maid of Elm Place	4	2–0–4–6	12	22
May Rose II	5	0–0–1–19	20	21
Daisy's Gem	6	0–0–3–10	13	16
Hayes Rosie	7	0–2–0–8	10	14
Richesse du Chene	8	0–0–3–6	9	12
Hayes Felois 2	9	0–2–1–3	6	11
Rose of Gold	10	0–0–4–3	7	11
Dolly Ada	11	0–2–0–4	6	10
Glenwood Girl II	12	0–2–0–4	6	10
Aluerdas Glenwood Queen	13	2–0–0–0	2	8
Dick's Lassie	14	2–0–0–0	2	8
Lillie of Iowa	15	2–0–0–0	2	8
Nellie Jay	16	1–1–0–0	2	7
Questa	17	0–1–0–4	5	7
Itchen Lily 5	18	1–0–1–1	3	7
Lady Beatrice of Lilyvale	19	0–2–0–1	3	7
Langwater Francaise	20	0–1–2–0	3	7

the class leaders, or 0.55 each, the remaining 668 cows being the dams of the remaining 59 class leaders, or 0.09 each.

The importance of the few outstanding families of Guernseys is again brought out by a study of these twenty high-scoring cows. Table XLIV shows them grouped into their respective families:

TABLE XLIV.—HIGH-SCORING GUERNSEY COWS IN FAMILY GROUPS

FAMILY	COWS' NUMBERS
May Rose	1, 5, 6, 7, 10, 18, 20
Dolly Bloom	2, 3, 17
Glenwood	12, 13, 16
Governor of Chene	8
Masher	15

Inbreeding and Relationship Values in Guernsey Class Leaders. Table XLV shows the inbreeding and relationship coefficients for such of the seventy class leaders as are inbred to any extent up to and including the fourth generation.

TABLE XLV.—INBREEDING AND RELATIONSHIP VALUES IN GUERNSEY CLASS LEADERS

Number	Name	Register number	Z_1	Z_2	Z_3	Z_{t_3}	K_1	K_2	K_3
1	Countess Prue	43785	0	0	6.25	3.0	0	0	0
7	Langwater Hope	27946	0	0	25	11.3	0	0	25
8	Lillia of Iowa 2	61500	0	0	6.25	3.0	0	0	0
9	Yeksa's Tops of Gold's Fannie	22362	0	0	6.25	3.0	0	0	0
10	My Fancy of Falcon Flight	42999	0	0	12.5	5.9	0	0	12.5
11	Edna of Mountain View	70827	0	0	12.5	5.9	0	0	0
12	Marshie D. V	67481	0	12.5	12.5	11.3	0	0	0
16	Criterions Clara Belle	76128	0	12.5	12.5	11.3	0	25	25
18	Masher's Countess of Dellwood	72081	0	0	6.25	3.0	0	0	0
19	Brownie of Linwood	60747	0	0	18.75	8.8	0	0	0
23	Pearl Rose of the Glen	47414	0	12.5	12.5	11.3	0	25	25
24	Winnie of Roughwood	96448	0	0	6.25	3.0	0	0	0
25	Langwater Zara	89273	0	12.5	31.25	20.6	0	0	25
29	Mixter Fairmaid	87594	0	0	12.5	5.9	0	0	25
31	La Noce's May Rose	91329	0	0	6.25	3.0	0	0	12.50
33	Cherub's Cora of Shorewood	83706	0	0	6.25	3.0	0	0	0
34	Pearl's Orpha	98424	0	0	6.25	3.0	0	0	0
36	Rochingham Maid	94933	0	0	12.5	5.9	0	0	0
38	Langwater Heroine	49483	0	0	18.75	8.8	0	0	0
40	Kantanah Glorianna	98643	0	12.5	12.5	11.3	0	0	0
44	Imp. Donnington Goldie 5th	59866	0	12.5	18.75	14.7	0	25	37.50
45	Golden Secret's Pearl	77034	0	12.5	12.5	11.3	0	25	25
46	Beacon Hill Rose Queen	97102	0	0	12.5	5.9	0	0	12.5
48	Lillia of Iowa 2	61550	0	0	6.25	3.0	0	0	0
50	Daisy of Chicona	94894	0	0	6.25	3.0	0	0	0
51	Brightness of Indian Bridge	85110	0	0	6.25	3.0	0	0	12.5
52	Nellie Jay of Pencoyd	77520	0	12.5	12.5	11.3	0	0	0
54	Langwater Hope	27946	0	0	25	11.3	0	0	25
55	Imp. Pearl of Rocque a Boeuf	94324	0	0	6.25	3.0	0	0	0
56	Emmadine Masherlette	109227	0	0	12.5	5.9	0	0	25
58	Jessebel of Edgmoor	52584	0	0	6.25	3.0	0	0	0
59	Mixter Faithful	101637	0	0	6.25	3.0	0	0	12.5
60	Guernest Ruth	76671	0	0	6.25	3.0	0	0	0
61	Procris Snowdrop	120156	0	0	6.25	3.0	0	0	0
62	Shuttlewick Levity	101850	0	0	25	11.3	0	0	25
63	Ultra of Edgemoor	107121	0	0	12.5	5.9	0	0	25
65	Ultra Celia	72478	0	0	12.5	5.9	0	0	25
66	Langwater Phyllis	70607	0	12.5	25	17.6	0	25	50
69	Merry Rose Maid	105929	0	0	12.5	5.9	0	0	12.5

It is seen that thirty-eight of these class leaders are inbred to some extent up to and including the fourth generation. None of them show inbreeding in the Z_1 or grandparental generation, and only six show inbreeding in the third generation. The group as a whole shows very little inbreeding, this amounting to 3.90 per cent of the total amount possible with full brother-and-sister matings. Most of the inbreeding is first discovered in the fourth generation back. Exactly 50 per cent of these class leaders that

are inbred evidence no K values whatsoever, indicating that in only half the cases was the same "blood" being concentrated on both sides of the pedigree.

Hunt and Turner's Study of Guernsey Cattle.—Hunt and Turner made a study of the leading sires of the Guernsey breed both from the standpoint of production and from that of show-yard winnings. Sires of daughters which had produced the equivalent of 1,000 pounds of butter-fat were scored 15 points, those with daughters which had produced the equivalent of 800 pounds of butter-fat 9 points, equivalent of 600 pounds, 4 points. The sire of the grand champion at the National Dairy Show (1910 to 1921) was scored 6 points, sire of a junior or senior champion 5 points, a first-prize winner 4 points, second-prize winner 3 points, third-prize winner 2 points, and fourth-prize winner 1 point. The following table is taken from Hunt and Turner's work:[1]

TABLE XLVI.—GREAT TRANSMITTING SIRES BASED ON BOTH SHOW-YARD WINNINGS AND PRODUCTION (*After Hunt and Turner*)

Rank	Name of sire	Registry number	Credits								
			15	9	4	6	5	4	3	2	1	
1	Imp. King of the May	9001	1	7	25	0	0	4	6	4	6	226
2	Imp. Hayes Cherub 2nd	25147	0	1	8	3	7	15	11	5	5	202
3	Ne Plus Ultra	15265	1	4	31	0	0	3	1	1	0	192
4	Imp. tord Mar	14359	0	0	11	3	3	10	5	1	0	134
5	Imp. ILchen May King	25174	0	1	8	1	2	7	6	4	2	113
6	Governor of the Chene	1297 P. S.	0	1	22	0	0	1	2	2	0	111
7	Beda's May King	11893	0	2	15	0	0	1	1	1	2	89
8	King of Chilmark	20798	0	5	8	0	0	1	0	2	0	85
9	Imp. May Rose King	8336	0	2	13	0	0	0	1	1	1	76
10	Jethro Bass	11366	0	2	13	0	0	1	0	1	0	76
11	Langwater Cavalier	21021	0	3	9	0	0	1	1	1	1	73
12	Jardinier's Masher	20957	0	2	8	1	1	2	1	0	0	72
13	Gold Lassie's Julian	27704	0	3	9	0	0	0	1	1	1	69
14	Langwater Royal	14253	0	2	10	0	0	2	0	1	0	68
15	Imp. Yeoman	8618	1	1	3	0	2	4	0	2	0	66
16	Imp. Galay's Sequel	16904	0	0	11	1	1	1	0	1	2	63
17	Dolly Dimple's May King of Langwater	12997	1	2	4	0	0	1	1	1	1	59
18	Lord Waukesha	10148	0	1	7	0	0	1	2	2	1	52
19	Bell Buoy of Linda Vista	19430	0	0	8	0	0	2	1	1	2	47
20	Ladock Cowboy	2785, E. G. H. B.	1	1	1	1	1	1	0	0	0	43
21	May King of Linda Vista	17946	0	0	6	0	0	1	2	3	0	40
22	Glenwood's Reputation	7687	0	0	6	0	0	0	1	1	1	30
23	Pretoria's King of Midlothian	22641	0	0	5	0	0	1	2	0	0	30
24	Masher	705 P. S.	0	0	5	0	0	1	0	1	1	27

[1] *Guernsey Breeders' Journal*, Feb. 1 and 15, Mar. 1 and 16, 1923.

The general similarity of this list with the one given in Table XLI is readily seen. In fact, fifteen of these bulls are to be found in the May Rose family, five in the Masher family, three in the Governor of the Chene family, and one in the Glenwood. In the Guernsey breed the producers of producers and the producers of show-yard winners are closely correlated.

Dairy-breed Class Leaders Compared.—The following table shows types of comparisons which may be made from the foregoing studies of the class leaders in each of the four dairy breeds. It is offered for the discussion it may stimulate, not for the issues it may settle.

TABLE XLVII.—COMPARISON OF DAIRY-BREED CLASS LEADERS

70 class leaders in	Average production, pounds		Per cent fat	Fat corrected milk, 4 per cent	Relative score
	Milk	Fat			
Jersey	14,895	876.01	5.88	19,098	75.3
Guernsey	16,047	849.07	5.29	19,195	75.7
Ayrshire	17,231	696.53	4.04	17,340	68.4
Holstein	26,800	974.18	3.63	25,333	100.0

70 class leaders in	Number inbred	Per cent of 70 inbred	Per cent inbreeding	Score of highest		Average score of all		No. scoring	
				Bull	Cow	Bulls (10 or more)	Cows (7 or more)	Over 10 bulls	Over 7 cows
Jersey	44	63	8.06						
Guernsey	39	55	3.94	73	49	20	14	25	20
Ayrshire	36	51	5.68	37	23	16	10	31	47
Holstein	39	55	3.31	43	29	17.5	11	34	27

The class leaders in the various breeds were selected for study since it is desirable to know the families and individuals capable of being stimulated to greatest production. No doubt many of these records are made under artificial, and expensive conditions. In many cases the animal is ruined for future production by one such experience. Frequently these record-breaking animals become sterile. It is to be hoped and expected that before long all breeds will be stressing the 10 months' test with a living calf produced in a reasonable time. This constitutes a solid foundation upon which any breed or breeder can build.

HERD SYNTHESES

The first requirement for the successful building of a herd is thorough knowledge of the breed. All breeds have strong and weak points, in all are to be found individuals, strains, and families which are superior to the mass. This knowledge should provide a short cut to success which any breeder can and should use. The methods of the great breeders in the particular breed under consideration should be studied. A study of herd sires in use at a breeding establishment for the previous 5 to 15 years

FIG. 78.—May Rose II, foundress of the May Rose family of Guernseys, noted for type as well as production. (*Photo. Courtesy Amer. Guernsey Cattle Club.*)

will give evidence of the sort of "blood" to be found in that herd. When the breed has been decided upon, and more especially the families in the breed, there only remains the procuring of desirable individuals and the wise intensification of the good points which the strain or family exhibits.

The Guernsey Herd at M. A. C.—As an example of breeding and herd building, the following study of the Guernseys at the Massachusetts Agricultural College, covering the period from 1910 to 1924, serves as a very good example. In 1910, the bull in service was Earl of Fair Acres, a grandson of Glenwood Boy

FIG. 79.—May Rose King, a great transmitting son of May Rose II.
(*Photo. Courtesy Amer. Guernsey Cattle Club.*)

FIG. 80.—Imp. King of the May, son of May Rose King, grandson of May Rose II.

of Haddon. The foundation cow in the herd in 1910 was Nantaska 4th, at that time a three-year old. Bred to Earl of Fair Acres, she produced Earl's Nantaska, whose 10-year average in milk, 7,464 pounds, is a little better than the 13-year average of Nantaska 4th, 7,173 pounds, though not quite so good in butter-fat, being about 25 pounds per year under that of the old cow.

The next bull that came into the herd was a gift from Langwater Farm, namely, Langwater College King, a son of Imp. King of the May, who has thirty Advanced Register daughters averag-

Fig. 81.—Langwater College King, a son of Imp. King of the May, great grandson of May Rose II.

ing 618 pounds of fat and fifteen Advanced Register sons. His pedigree follows on page 258.

The bull, Imp. King of the May, was a son of Imp. May Rose King, the latter, in turn, a son of the renowned Claremont May Rose. The breeding plan has been formulated to perpetuate and increase this May Rose blood, particularly through offspring from Imp. King of the May. Langwater College King left six daughters in the herd. Three of these were out of Earl's Nantaska and in comparison with their dam, who has a 10-year average of 7,464 pounds of milk and 352 pounds of butter-fat, they have averaged 10,600 pounds of milk and 500 pounds of

FIG. 82.—Pedigree of Langwater College King, the first May Rose bull in the M. A. C. herd.

butter-fat. The six daughters of Langwater College King produced, as an average for twenty-three lactations, 10,314 pounds of milk and 476.6 pounds of butter-fat, whereas their dams had produced in fifty-one lactations an average of 6,554.1 pounds of milk and 313.7 pounds of butter-fat. The best record to be found among the daughters of Langwater College King is one of 19,152 pounds of milk and 888 pounds of butter-fat, while the best record among their dams was 13,354.9 pounds of milk and 704.5 pounds of butter-fat. Langwater College King carries 25 per cent of the "blood" of Imported May Rose King and he has five Advanced Register daughters with an average of 12,121.8 pounds of milk and 596.01 pounds of fat.

The next bull that came into the herd was Dean of the May. On page 260 is appended his pedigree.

His pedigree shows that he is also carrying considerable May Rose King "blood," his immediate sire being out of a full sister to Imp. King of the May. This gives Dean of the May 12½ per cent of the "blood" of Imp. May Rose King. Also one of the paternal great granddams of Dean of the May was the maternal granddam of Langwater College King. Dean of the May has nineteen A. R. daughters. He left two daughters out of daughters of Langwater College King out of Earl's Nantaska. These two daughters have just completed their first lactation period. One produced 9,914 pounds of milk and 454 pounds of butter-fat, equivalent to about a 14,000-pound mature record. The other produced 9,323 pounds of milk and 450 pounds of fat, equivalent to about a 13,000-pound mature record. They thus have two-year-old records of about 9,600 pounds of milk and 450 pounds of butter-fat in comparison with an average of 9,300 pounds of milk by their immediate dams as mature cows and a 10-year average of 7,464.4 pounds of milk and 352.3 pounds of butter-fat by their granddam, Earl's Nantaska. The daughters of Langwater College King carry 12½ per cent of Imp. May Rose King "blood," while the daughters of Dean of the May out of daughters of Langwater College King carry 18.75 per cent of the "blood" of May Rose King. They also are inbred to the extent of 18.75 in the fourth generation back. Dean of the May also left another daughter out of a daughter of Langwater College King. This daughter of Dean of the May has a two-year-old record of 11,447.3 pounds of milk and 518.7 pounds of butter-fat, equivalent to a mature record of around 15,000 pounds of milk and about

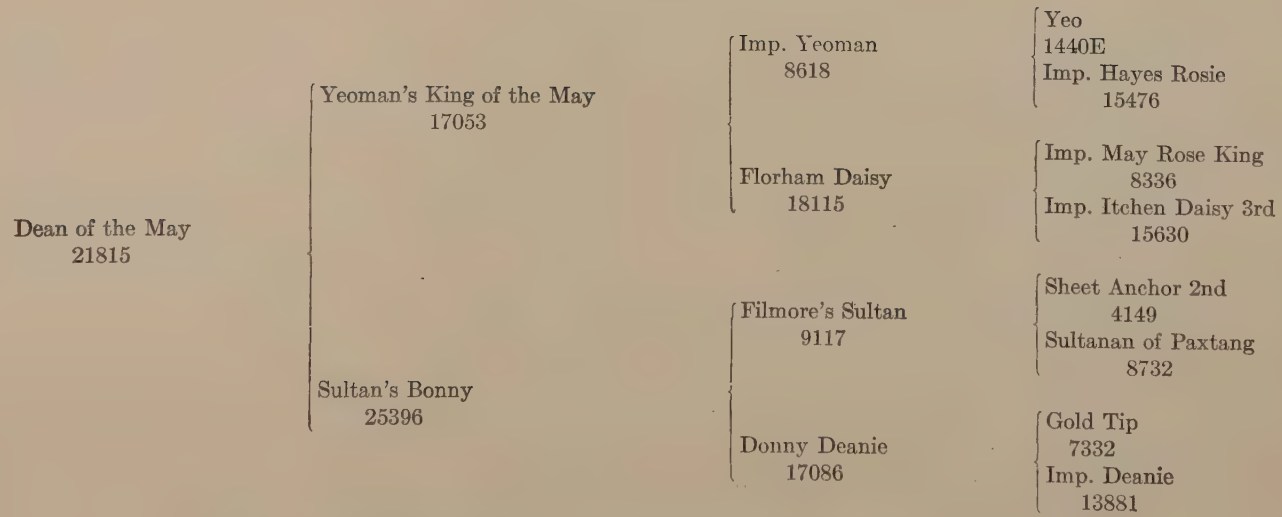


FIG. 83.—Pedigree of Dean of the May, the second May Rose bull in the M. A. C. herd.

650 pounds of fat in comparison with her dam's six-year average of 7,530.55 pounds of milk and 338.8 pounds of fat. This daughter of Dean of the May also carries 18.75 per cent of Imp. May Rose King "blood" and is inbred to the same extent in the fourth generation back. In all, Dean of the May left five daughters in the herd. Dams of these five daughters of Dean of the May in twenty-four lactation periods averaged 7,783.2 pounds of milk and 372.1 pounds of butter-fat. To date these five daughters have had one lactation period each. They have produced on

Fig. 84.—Mixter May Royal, a son of Langwater College King, great great grandson of May Rose II. He sold for $23,000 at the Mixter Farm dispersal sale.

the average 8,892.7 pounds of milk and 437.3 pounds of butter-fat as two-year-olds, or the equivalent of around 12,700 pounds of milk and 624 pounds of butter-fat as aged cows.

The next bull brought into the herd was Mixter May Royal. This bull was a son of Langwater College King, a former herd sire, and out of Yeoman's Mixter Charm, a half sister to Dean of the May, the bull which Mixter May Royal succeeded. The pedigree of Mixter May Royal follows.

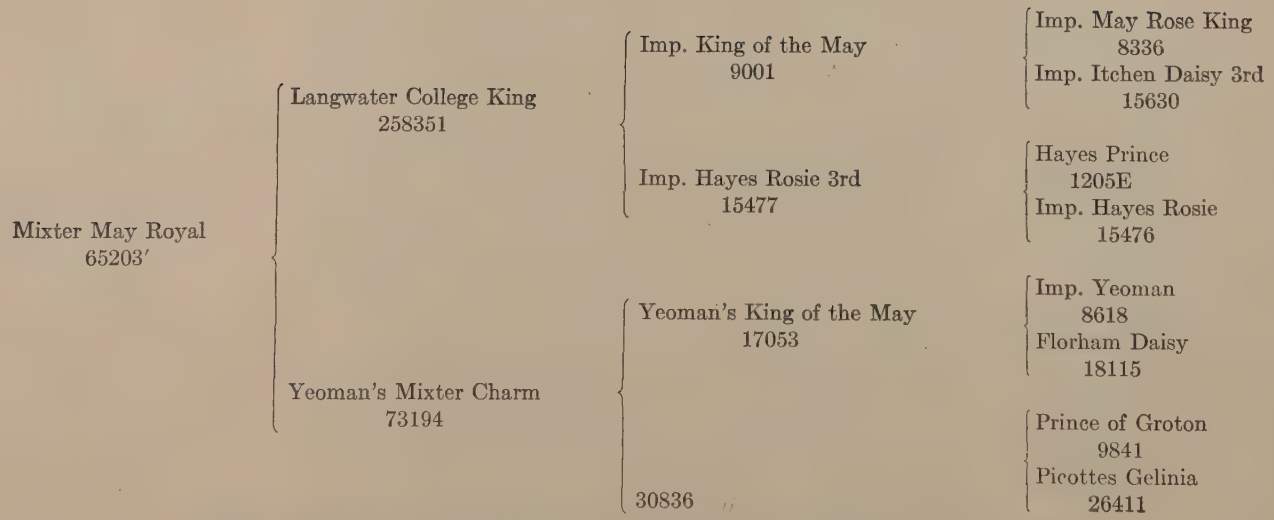


Fig. 85.—Pedigree of Mixter May Royal, the third May Rose bull in the M. A. C. herd.

This bull, therefore, on both his sire's and his dam's side, traces to Imp. May Rose King and carries 18.75 per cent of Imp. May Rose King's "blood." He was used on the daughters both of Langwater College King and Dean of the May, the former animals, therefore, carrying 15.62 per cent Imp. May Rose King's "blood" and the latter 21.87 per cent May Rose King's "blood." None of these heifers have as yet completed records, so no direct comparison can be made. Daughters of Langwater College King, bred to Mixter May Royal, give an example of close breed-

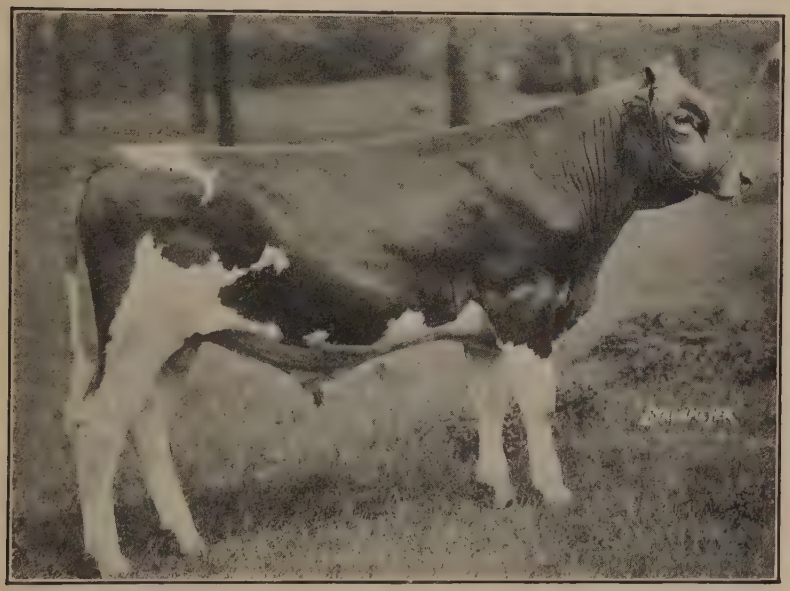


FIG. 87.—Mixter Thor a son of Mixter May Royal, great great great grandson of May Rose II. Present Guernsey herd sire at Mass. Agri. College.

ing as both the sire and the dam of such animals are, respectively, sons and daughters of Langwater College King. Daughters of Dean of the May out of daughters of Langwater College King, bred to Mixter May Royal, give an example of linebreeding, such animals having on their sire's side one line tracing to Imp. May Rose King and on their dam's side two lines tracing to this bull. It was impossible to keep Mixter May Royal as long as desired, because his donor, Mixter Farm, desired his services on daughters of Langwater College King. Mixter Rover was then secured from Mixter Farm. He is by Langwater Fisherman a son of

Fig. 86.—Pedigree of Mixter Rover, the fourth May Rose bull in the M. A. C. herd.

Imp. King of the May, and out of Yeoman's Mixter Trilby, a half sister to the bull, Dean of the May. His pedigree appears on page 263.

Mixter Rover, accordingly, traces also on both sides to Imp. May Rose King and carries 18.75 per cent of the "blood" of Imp. May Rose King. He has not been in the herd long enough to have left any offspring. He will be bred to daughters of Langwater College King, which will give offspring with 15.62 per cent of Imp. May Rose King's "blood," also to the daughters of Dean of the May, out of daughters of Langwater College King, which

FIG. 88.—Mixter May Princess, grand champion Guernsey cow at the National Dairy Show 1924, a daughter of Langwater College King.

will give 9.37 to 12.50 per cent of Imp. May Rose King's "blood," and also to daughters of Mixter May Royal out of daughters of Dean of the May, which will give 12 to 13.62 per cent of Imp. May Rose King's "blood."

It is possible to compare two of the bulls, namely, Langwater College King and Dean of the May. Three daughters of Langwater College King were bred to Dean of the May. These three daughters of Langwater College King in fourteen lactation periods averaged 8,804.5 pounds of milk and 420.4 pounds of butter-fat. Three daughters of this breeding by Dean of the May have com-

pleted lactation periods in which they averaged 10,200 pounds of milk and 474 pounds of butter-fat as two-year-olds, equivalent to mature records of about 14,500 pounds of milk and 650 pounds of butter-fat.

The pictures through the text indicate the type of animals left by the various bulls. In general, it may be said that daughters of Langwater College King were of good Guernsey type, daughters of Dean of the May, while an improvement in production, were a retrogression in type. Daughters of Mixter May Royal and of Mixter Rover give promise that they will be quite true to accepted Guernsey type.

FIG. 89.—Four of the get of Mixter May Royal.

The Berkshire Herd at M. A. C.—The same general breeding policy is also being used with the Berkshire swine at the Massachusetts Agricultural College. A large majority of the sows in the herd are descended from Lord Premier's Successor, a boar that was grand champion in 1914 and the champion sire in 1915, 1916, and 1917. The blood lines trace through Longfellow Double, a son of Lord Premier's Successor, this son being grand champion in 1915, 1917, and 1921; and also through a son of Longfellow Double, namely, Double Rival Champion 2nd. The latter boar was bred at Hood Farm and was later owned by Mr. Carleton of Rowley and still later by Mr. Packard of Brock-

ton. This boar was grand champion at Brockton fair for 2 successive years. He was an excellent individual, strong, stretchy, and of excellent quality. There are two of his daughters, old sows now, and six granddaughters in the herd at present. Desiring to linebreed in the Berkshires, a good son of Double Rival Champion 2nd was secured to mate with his daughters and granddaughters. This boar's name is Dreamwold's Dinah's Double, bred by R. W. Packard and owned at time of purchase by Douglas Lawson. The results this far have been very gratifying. With such breeding, large litters have been produced, up to twelve, all of which were raised, and a

FIG. 90.—Longfellow's Double, a Grand Champion Berkshire boar in 1915, 1917 and 1921.

uniform lot of good-quality, stretchy pigs have resulted. The plan is to continue breeding in this Lord Premier's Successor line and also to develop another line, namely, the Pearl Successor 8th line, breed closely in these two lines, and then cross the two lines.

Use of Inbreeding in Herd Syntheses.—It has been clearly demonstrated that in plant breeding there is a distinct advantage in intense inbreeding in order to bring about uniformity and homozygosity of factors. This inbreeding is often accompanied by loss of size and vigor, but when two such inbred strains are crossed the progeny is much superior to either original parent. This scheme has been carried one step farther, starting with four inbred strains, crossing the two pair, and then crossing the resulting hybrids. This has given very gratifying results. Such a method should be feasible with animals. Brother-and-sister

matings for a few generations (four or five) should give an opportunity for the recessive factors to segregate out in very undesirable animals, which may be disposed of. Two such lines in a preponderently dominant homozygous state when mated together should produce very desirable offspring. The great drawback to ordinary breeding (usually out-crossing) is that it gives no chance for getting rid of the recessive undesirable characters. In such a system these will be carried along indefinitely.

Bakewell made a notable contribution to animal breeding and achieved lasting fame because he dared to inbreed. Some animal breeder will one day emulate Bakewell's example, carry it one step farther after the pattern of the plant inbreeding cited above, and so carve his niche in the animal breeding hall of fame.

CHAPTER XVIII

DEVELOPMENT

The idea is far too prevalent that the breeder's task is completed when two animals carrying desirable germplasm are mated. As far as animals are concerned, there are two major influences shaping their destinies. In the first place, there is the matter of the kind of germ cells uniting to produce the new individual. Preceding chapters have dealt with this subject. This matter of *inheritance* is of first importance. The triangle of life, inheritance, environment, and training, does rest on inheritance as the basic influence. All three are important, but the one which actually brings into being the possibilities for the individual is inheritance. No amount or kind of subsequent feeding and care can ever make good the deficiencies of a poor hereditary beginning. The converse of the last statement is, of course, also perfectly true, namely, that a good hereditary beginning is powerless to overcome the effects of subsequent improper feeding and lack of care. In other words, *management,* which is the second major influence shaping the destiny of animal life, is the complement of inheritance and of nearly equal importance. It is unwise to lavish good feed and studied management upon animals, the very nature of whose hereditary complex precludes the possibility of their ever making just returns for the efforts expended upon them. Conversely, it is just as unwise, if not more so, to deny, through poor feed and management, the full expression of characters inherent in an animal whose parents endowed it with a favorable hereditary complex in the beginning. The stock of high class germplasm is none too large, but herein lies not the greatest lack; it lies in the fact that breeders in so many cases fail to develop to the full extent the inherent capabilities of their animals.

Initiation of Development.—A trite and time-worn saying which, however, needs almost daily reiteration is to the effect that development starts the moment the ovum is fertilized. Previous to that time the breeder's influence over the individual that

is to be is not great and consists of two elements: First, he has control through selection of the animals that are to be parents to the individual he has in mind, and, second, he can through proper feeding and good management contribute to the strength and virility of the germ cells these parents are producing. The possibilities of the new individual are complete and sealed the moment fertilization takes place, and are, of course, dependent upon the chromosomal make-up of the ovum and spermatazoön that have united. The breeder's concern from that moment on should consist of providing the feed and environment that will bring out all the inherent good contained in the germplasm. To do this successfully, he must know, and work in conjunction with, the physiological laws underlying the growth of an animal both in its pre- and post-natal life.

Maternal Influence.—During prenatal life the animal is subject to many influences through its mother. Maternal impressions have already been considered and dismissed as highly improbable, in spite of the fact that as noted an Angus breeder as McCombie subscribed to such a belief and, in order to insure the production of black calves, painted his buildings, fences, etc, black. This does not mean to say that the well-being of the pregnant female can in any way be neglected. On the other hand, it is possible and profitable to do many things for such an animal which will have a direct bearing on the production of strong, viable offspring.

Management of Breeding Females.—In the first place, it must be realized that reproduction is work requiring the expenditure of energy on the part of the mother. Common sense will indicate that a double duty cannot be put on such animals with the expectancy that both duties will be accomplished successfully for any great period of time. This applies particularly to mares and dairy cows. True, the strain of reproduction is not heavy in early pregnancy, thereby leaving most of the animal's powers free for productive purposes. As the gestation period progresses, however, the pendulum swings gradually the other way. A mere statement of the way in which an embryo develops should suffice to prove this. The bovine embryo at 3 months is about 5 inches long, and weighs less than 1 pound; at 4 months, it is 10 inches long and weighs from 3 to 6 pounds; at 5 months, it has grown to a length of about 15 inches and has reached a weight of approximately 8 pounds. The gestation period is now more than one-half completed and in the remaining 4 months the fetus will grow

to 3 or 4 feet in length and attain a weight of 50 to 100 pounds. The teaching should be evident, namely, that if worth-while offspring are desired the demands on the mother for productive purposes during the last half of pregnancy must be in an ever-declining ratio to those for reproduction. Every dairy cow should have a dry period of at least 6 weeks to 2 months previous to calving. Feeding should be liberal during this period, for two purposes; first, that of allowing the cow to bring into the world a healthy, strong calf; and, second, of enabling her to build back into her system the depleted stores of protein, mineral material, etc., that for 10 months she has been daily depositing in the milk pail. Numerous experiments have abundantly proved that such practice pays big dividends to all concerned. Every pregnant female should have a fairly liberal amount of moderate exercise. This is particularly true of brood mares, which, even while heavy in foal, can with benefit perform many light tasks about the farm. Heavy work of all kinds, particularly that requiring sudden straining, should be carefully avoided. Sporadic abortions are brought on by such things as slipping, jumping, butting, crowding through narrow doorways, kicking and slapping by attendants, exposure, and many other untoward incidents. The aim of a breeder should be to make his breeding females of any class comfortable, though this in no way should be construed to mean pampering. It is possible to overdo anything in two directions. The aim at all times therefore should be to seek out and follow the happy medium, particularly as regards work, production, and the general environmental conditions under which the animals live. No man can hope to be a successful breeder who fails to realize to the fullest extent of which he is capable the work and care, physical and mental, which every female must expend for the perpetuation of the species.

Feeding of Breeding Females.—Equal in importance with care is the consideration of feed. It is advisable to inquire as to the chemical make-up of the new-born and to remember that the mother cannot supply any ingredient to her developing offspring that is not furnished in her feed or else is present in her own body. When born, the young of all species consist of from 70 to 80 per cent water and from 20 to 30 per cent dry matter. This dry matter is made up very largely of protein and minerals, with a small percentage of fat. Eckles and Trowbridge at the Missouri Agricultural Experiment Station found an 80-pound new-born

calf to contain 14 pounds of protein, 2.8 pounds of mineral matter, and 2.5 pounds of fat. The protein furnished to pregnant animals should come from several desirable sources. There should be a variety of proteins, so that the deficiencies, if any, in amino acids may be compensated for by another more abundant source, a question which will be discussed fully in a later section of this chapter. The 2.8 pounds of mineral matter in the new-born calf consist very largely of calcium and phosphorus, which two ingredients make up approximately 90 per cent of the weight of bone. The four nutritional requirements of animals, namely, energy, proteins, minerals, and vitamines, are all very essential for pregnant females. These animals should be in a gaining condition when bred and should continue to gain right through the gestation period, the aim being the happy medium between starvation and obesity. The energy supply (carbohydrates and fats) should be abundant for both productive and reproductive purposes, be properly balanced with high-quality protein from at least three or four sources, and, if necessary, the ration should be supplemented with minerals and vitamins. If legume hay is being fed, the problem is much simplified, because, besides yielding a good supply of energy, legumes are high in well-balanced proteins and rich in calcium and vitamins. If legume hays are lacking, the problem is more difficult, but through the use of high-class proteins, these usually also being rich in phosphorus, and possibly supplemental minerals, such as bone meal and limestone, and with plenty of good-quality hay and pasturage, success may be attained. It is essential to avoid spoiled feeds of all kinds, and poisonous substances, such as ergot, a fungus sometimes found in rye; to avoid sudden changes in diet; and to prevent pregnant females from getting an overdose of salt. Any of the above are likely to bring about physiological disturbances resulting in abortion. Also it should be borne in mind that with young females which have not yet themselves attained full growth the supply, particularly of protein and minerals, should be increased. As revealed by the experiments of Mumford, the gestation period actually increases the rate of growth of young females, while the subsequent lactation period is a serious drain on the resources of these animals, retarding their growth markedly. Judgment must be used in determining how regularly and continuously young females are to be bred before they themselves have had opportunity of reaching full development. If permanently

stunted through overwork in reproduction while young, there is no danger of this characteristic continuing in their offspring, provided, of course, the offspring are not stunted for the same reason. Stunting, however, is not a wise practice, since no underdeveloped animal can function to the fullest extent in reproduction, size in itself being an important factor. Having thus, in the first place, selected desirable germplasm for the genesis of his animals, and having furnished the very best feed and

FIG. 91.—The cow (above) was fed a balanced ration made up of wheat straw, wheat meal and wheat gluten in 1907. She was in poor condition and gave birth prematurely to the calf (below) which died. In this ration energy and proteins are taken care of, minerals and vitamins are deficient. (*Photo. Courtesy Wis. Agr. Exp. Sta.*)

care to the mother during gestation, the breeder is now ready for the birth of the new individual.

Preparation for Parturition.—The question immediately arises as to the exact day on which to expect the new arrival. It is essential for any constructive breeder to know the date on which the female was served. This, along with a knowledge of the normal gestation period for the class of stock in question, will give the desired information. Animals should be placed in

individual pens or stalls at least a week before parturition. This is essential if trouble is to be avoided, though it should not be taken to mean that the animal is to be put into a stall or pen and left there without exercise for the week previous to parturition. Such a practice would add largely to the normal difficulties which the female has to overcome at this time. The stall or pen should be thoroughly cleaned and disinfected before use and so situated as to prevent drafts. If proper precautions have been taken, if the females have not been overfed, if their bowels have

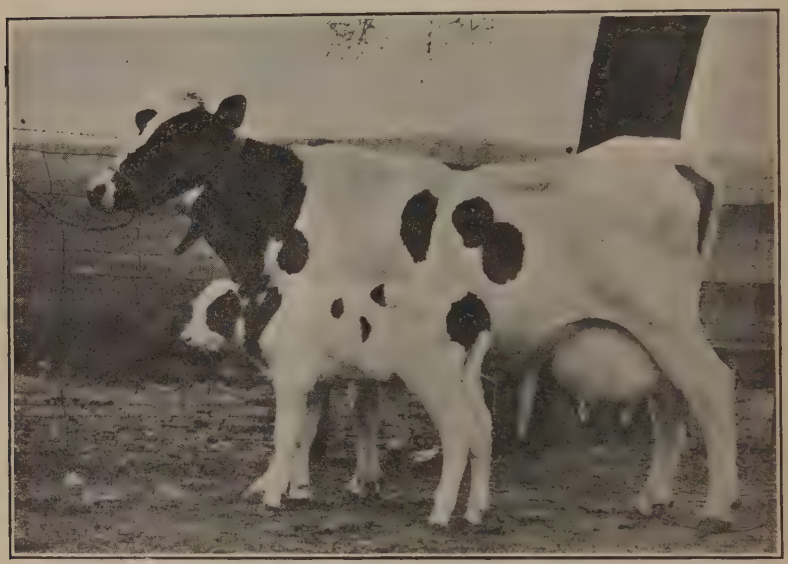


FIG. 92.—This cow was fed the same sort of ration in 1924 as the cow shown in Fig. 91 but got in addition 2 per cent bone meal and 2 per cent raw cod liver oil. The results are apparent. (*Photo. courtesy Wis. Agr. Exp. Sta.*)

been kept moderately loose, and if a clean, roomy stall has been provided—assistance will seldom be necessary or advisable. Occasionally, of course, it is, and then the first consideration is quietness and kindness. If young are properly presented, strength merely being lacking for complete expulsion, aid may be given by pulling outward and downward in unison with the mother's attempts at expulsion. Wrong presentations must be ascertained quickly and aid given or a veterinarian called before the mother's strength is entirely consumed in futile attempts to deliver the young. The critical stage of parturition safely passed, attention should be turned immediately to the task of supplying the young

with the food ingredients which will both quantitatively and qualitatively assist in its full development. A minutely detailed discussion of the proper rearing of colts, calves, pigs, and lambs cannot be entered into, but since the general principles are the same in all classes of livestock a general discussion should suffice.

Feeding the Young.—It is generally recognized that milk is the best food for growing animals, and when it is considered that milk was originally designed for that purpose it does not seem surprising. An inquiry as to the why and wherefore may prove enlightening. In the first place, milk must supply all the essentials for growth, namely, energy, proteins, minerals, and vitamins, without any one of which growth, at least maximum growth, is impossible. The energy supply of milk is contained in the carbohydrates (milk sugar and butter-fat). The proteins of milk are abundant and of very high quality, being especially rich in lysin an amino acid, which is necessary for growth. The minerals, calcium and phosphorus, required in the growth of the skeleton are present in good quantity, as are also the latest-discovered members of the nutrition family, namely, the vitamins. Add to the above the fact that milk is palatable and easily digested, and it will readily be recognized why it is so difficult to find a satisfactory substitute for it as far as growing animals are concerned.

Energy for Development.—The energy supply which comes very largely from carbohydrates and fats, should be abundant in the feed of young animals, should be fairly easily digested, and, for the sake of economy, be derived from as cheap a source as possible. The function of energy in the body is to keep up the body temperature, to keep the vital organs functioning, and also to play its part in the growth of the individual. Corn is the greatest energizing feed and is followed more or less closely by the other grains, such as barley, oats, wheat, and rye. Energy is also furnished in such materials as hay and silage.

Proteins for Development.—Until 1900 it was generally supposed that proteins were all alike qualitatively. During the French Revolution the idea of using gelatin, a protein extracted from bones, was conceived and the material given a trial. When used as the only source of protein it proved in all cases insufficient for normal well-being, though the reason was not learned until many years later. Drs. Osborne and Mendel at New Haven, fed rats a perfectly balanced ration but with the protein all in the form of

zein, the principal protein found in corn. Rats so fed were unable to maintain their weight. Upon the addition of typtophane, one of the amino acids that go to form complete proteins, the animals were enabled to maintain their weights, but they failed to grow satisfactorily until some lysin, another amino acid abundant in milk, had been added. The gelatin and zein, while both proteins, failed to permit maximum growth and well-being because they were not complete proteins, but were deficient in certain of the amino acids. All the eighteen or twenty amino acids are necessary for maximum growth and, while amino acids are not yet fed as such, one can and should provide his animals an abundant supply of protein and it should come from different plant and animal

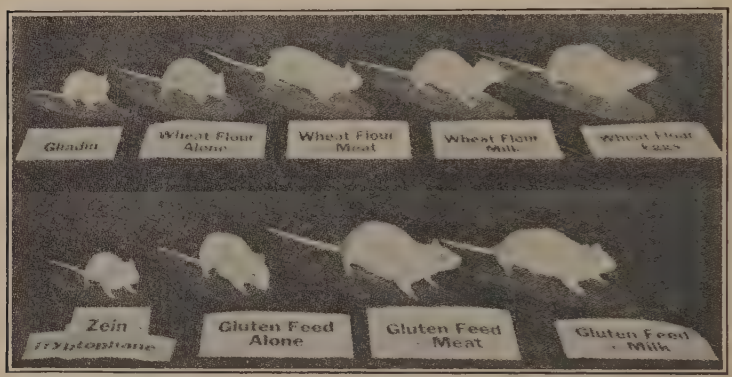


FIG. 93.—Showing the effects of different proteins in stimulating growth. All the rats in the picture were fed balanced rations. (*Photo. courtesy Drs. Osborne and Mendel.*)

sources, so that the deficiencies of one source may be made good by some other. The best sources of proteins are milk, legume hays, linseed-oil meal, wheat bran, and tankage.

Minerals for Development.—As mentioned previously, mineral matter is essential for normal growth and well-being and may be supplied from such sources as legume hays, mill feeds, grains, and through the use of such substances as bone meal, ground limestone, charcoal, and so on. Cows doing poorly, possibly aborting, have done better and ceased aborting when supplied with ground limestone and bone meal, though there is no scientific proof that the use of these minerals affected the cure—it might have come without their use. One per cent of minerals in the feed, however, will do no harm and may do some good, especially

where legume hays are not available. It is well to bear in mind that the common farm grains are low in minerals, particularly sodium and calcium, as well as being poor sources of proteins and of vitamins.

FIG. 94.—Pigs suffering from rickets because of a deficiency in lime and phosphorus or a deficiency in Vitamin D or both. (*Photo. courtesy Wis. Agr. Exp. Sta.*)

Vitamins for Development.—Five vitamins have been discovered, which have an effect on the normal growth and development of animals. The first, called fat-soluble A vitamin, is

FIG. 95.—Xerophthalmia in the dog due to a deficiency of Vitamin A. This vitamin is also a growth promoter. (*Photo. courtesy of Wis. Agr. Exp. Sta.*)

found in butter-fat, yolk of egg fat, glandular tissue, such as livers and kidneys, and also, fortunately, in pasture crops and hays, if the latter have been properly cured and not allowed to

bleach. A lack of this vitamin causes a disease of the eyes known as Xerophthalmia as well as an inhibition of growth. Vitamin B or water-soluble B, is found in yeast and generally in unprocessed foods and feeds. A lack of this vitamin retards growth and causes a loss of appetite as well as a disease known as beri-beri. Vitamin

FIG. 96.—A rat showing the effects of a deficiency of Vitamin A in the ration (*Photo. courtesy Drs. Osborne and Mendel.*)

C is found in fresh foods and feeds and is generally abundant in fruits. A deficiency of it causes (in man) a disease known as scurvy, which does not affect farm animals. Another vitamin, designated D, has been suggested as the agent which enables an

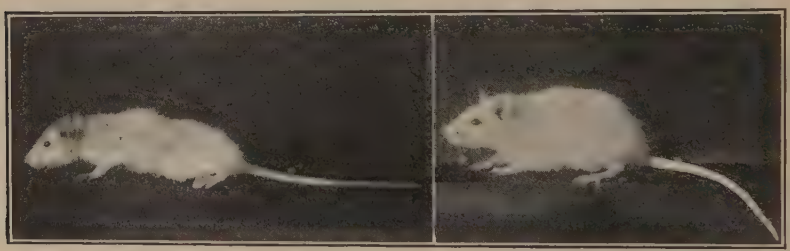


FIG. 97.—A rat before and after receiving a supply of Vitamin B. (*Photo. courtesy Drs. Osborne and Mendel.*)

animal to assimilate calcium and avoid rickets. It is said to be found especially in pasture grass and in cod-liver oil. Vitamin E has been discussed in Chap. VI.

For maximum growth, animals must have all of the above-mentioned ingredients in their feed. The most abundant sources are as follows:

Energy—grains, silage, hays, especially legume hay.

Proteins—milk, legume hays, linseed-oil meal, wheat bran, tankage, grains.

Minerals—legume hays, mill feeds, bone meal, and ground limestone.

Vitamins—legume hays, pasture crops and grasses, oranges, eggs, yeast, milk, and cod-liver oil.

Nutritional Requirements.—The nutritional requirements of growing animals are very different from those of fattening animals. In growing animals one is attempting to build a large, bony framework and to develop the corresponding muscular structure and also to increase the size of the vital organs. This means that relatively more protein and less energy must be fed than in fattening, that the mineral constituents must be relatively larger, and that the growth promoting vitamins must be furnished in abundance. It is well to bear in mind that the nutritive ratio of cow's milk is 1:4. In making up rations for young, growing animals one should attempt to approximate this figure. Skim milk, however, has a nutritive ratio of 1:1.5, that is, it is relatively higher in protein and can best be supplemented with ordinary farm grains. The aim with young breeding stock is not to have them grow fat but rather to stretch out and grow big frames on which fat can be deposited later.

Environment and Training.—The environment, in general, should be in keeping with the end sought. This will vary somewhat with the class of stock in question. For all classes, however, the surroundings should be sanitary, the animals made comfortable, and provided at all times with an unlimited supply of clean water. Fattening animals should have only enough exercise to keep them in good condition. The future breeding animal, however, requires abundant exercise, which will have a fourfold effect: (1) it will conduce to growth of frame, (2) it will conduce to strength and vigor, (3) it will increase the appetite, and (4) it will promote general health.

It is essential that colts and calves be taught to lead and in other ways submit to their owner's desires while they are still young and impressionable. If intended for show purposes they should early be taught to stand so as to show to best advantage. Feet in particular need constant care and attention to prevent crooked legs. Breeding females of all classes, particularly cattle, must have sufficient roughage while young to induce maximum

development of middle, though care is necessary that they do not grow pot-bellied. If left unbred for too long a period females may become permanently sterile.

Conclusions on Development.—The growth impulse in animals is greatest while they are young, and it is at this stage that the cheapest gains can be secured. Advantage should be taken of this fact and the animals kept in good condition and gaining rapidly from the day of birth, but they should not be overfed, causing scours. If scours do occur, feeding should be stopped immediately and remedies given, as feed given a scouring animal will not be assimilated, but will aggravate the trouble. It is always a good plan to keep young animals a little hungry, thus avoiding scouring troubles, though it is obvious that no animal can grow without liberal feeding on properly balanced nutritious feeds supplying all the requirements. No man will ever be a successful developer of animals unless he be a keen observer, quick to detect the first indication of scours or other troubles and quick also to combat them. No young should ever be fed without first looking to see the character of their droppings.

For maximum growth animals must be the result of mating healthy parents, the mother must be provided with the necessary elements for development of the embryo, and after birth the food ingredients and environmental conditions that will bring out all the inherent possibilities in the offspring must be supplied. The best food for the young is its mother's milk, which through proper feeding may usually be made abundant. If this is impossible such an animal should be eliminated from the breeding herd or flock. Milk should be supplemented as soon as possible with nutritious palatable grains, legume hays, and pasturage and the growth impulse, so strong in all young, utilized to its fullest extent. Capacity to handle large amounts of feed efficiently is a characteristic of improved breeds of livestock. The greatest economical use of this attribute demands the full development of the animal, which can only be obtained through a knowledge of and cooperation with the physiological and environmental laws underlying growth.

CHAPTER XIX

FITTING FOR SALE AND SELLING

The breeder's job does not end with the creation and development of superior stock; he must also market his product. The very top-notch animals will perhaps sell themselves, but this is not true of the general run of animals produced. It requires salesmanship, an art in itself, to get the true worth of the animals produced. Many animals are sold for a great deal less than they are worth and many others for much more than they are worth, the causative factor in each case being the kind of salesmanship employed.

Cardinal Point—Good Animals.—Sales should be planned years in advance, by which is meant that the best way to insure profitable sales is to use due care in the selecting and mating of an animal's parents and grandparents so that the offspring will be an animal of real merit. This matter of proper selection, as has already been pointed out, is the key to the whole of the breeding industry. Without judicious selection, subsequent development and sale are bound to suffer. The breeder, to be in any true sense successful, must possess imagination and vision, which, coupled with common sense, study, and an indomitable spirit, will eventually place him in the first rank. The requisites and the only insurance for continued successful sales are excellence of animals and a reputation for reliability. There are numberless little tricks of the trade which must receive due attention, but the criterion of any sale is the type of animals offered. If it is of uniformly high excellence, the breeder need have no fear for the ultimate success of his venture.

Fitting for Sale.—An animal's value can be enhanced greatly by proper fitting. First of all, it should be recognized that proper fitting requires months, not weeks. When the parents have been carefully selected and the offspring developed to the maximum from the day of birth on, the aim should be to keep the animals in fairly good condition at all times and then to allow at least 3 to 5 months to get them into final shape for selling. Recall the peach

grower who when asked "What do you put that little sprig of green leaves on top of each basket of your peaches for?" replied "Oh, for about 25 cents a basket." There is no last-minute little trick that will add $50 to a heifer's worth as she starts for the ring. The proper fitting of animals is a gradual process. It must be started in ample time and progress gradually up to the day of sale. General guides for fitting can be cited, but because of the difference in men as well as in animals no hard-and-fast rules for feeding or other care can be laid down. The common tendency

FIG. 98.—The Grand Champion Southdown ram at the 1925 International, shown by Mountain Farm, Bradstreet, Mass.

is to start too late and then to try to hurry the job. If the animal stays on feed, such fitting usually falls short because it is only rarely that it gives an even, firm quality of flesh and animals so handled are more than apt to appear logy and disinterested on the very day that it is desired to have them appear bright, alert, and at their best. The fitting plan should include ample time for exercise and grooming. The exercise will keep the animals feeling well, conduce to a good appetite, lay the flesh on smoothly, and give it the firm quality so much desired. Grooming is essential because it improves the animal's appearance and also stim-

ulates the skin and thus aids it in its excretory function. Blanketing is also an aid both in keeping the coat clean and adding to its glossiness. Cleanliness through the use of soap and water should go without saying, as should also the matter of an abundance of good, clean water for drinking purposes, as this is a great aid in promoting general health and the elimination of waste. For the sake of cleanliness as well as looks, a clipping machine should be used wherever necessary, especially with cattle. The tail should be clipped down to the switch, and the latter

FIG. 99.—Auchenbrain White Beauty 2nd owned by Penshurst Farm, a splendid example of dairy type.

braided and fluffed up. The appearance of the rear quarters and the face and neck are also often improved through clipping. The clipping machine and shears can be used to accentuate good points or breed characteristics and also to minimize faults. Such practices are quite general and do no harm, because they enhance the animal's appearance and no keen observer need be misled.

Feeds Useful in Fitting.—Feeds indicated at this time are good pasturage, legume hays, silage and roots, and a good grain mixture, including some linseed-oil meal and wheat bran.

For cattle of all ages, Prof. E. S. Savage, of Cornell, advises the following ration:

200 pounds of hominy or corn meal.
100 pounds of wheat bran.
100 pounds ground oats.
50 pounds oil meal.

"In addition, a liberal use of dried beet pulp and molasses, the beet pulp soaked in water and molasses at the rate of 10 quarts of water to 1 quart of molasses."

FIG. 100.—Morton Mains Lord Barrylyndon, the grand champion Ayrshire bull at the 1920 National Dairy Show, owned by Alta Crest Farm, Spencer, Mass.

Any feeding plan or ration should have as its goal the gradual improvement of the animal's condition right up to the day of sale. A serious mistake is often made in speeding up the fitting so that the animals reach their best condition some time previous to the sale and then go stale. This should be avoided, as it will be better to have them a little underconditioned, but still gaining, rather than to have them overdone.

Care of Feet.—The feet should always be trimmed back fairly short and shaped up well with a chisel, rasp, or emery, as the animals will look much better if standing well up on their toes.

The feet and horns, if present, should be cleaned thoroughly, scraped, and polished with linseed oil or a metal polish.

The animals must be tractable in the ring, which comes only with the proper amount and kind of handling. They must be accustomed to being led and taught how to come up into proper position with fore and hind feet placed evenly and stretched to such a degree as will show them at their strongest.

Advertising.—A certain amount of advertising should be carried on, and it is essential that it be so timed and placed as to bring maximum returns. Because of the great diversity of conditions to be met, no hard-and-fast rule can be laid down. The first question to be answered is, Whom does the breeder wish to reach, or from how great a distance may he reasonably expect buyers to come? The answer depends on the class of animals offered, the breeder's reputation, the animals individual merit, the condition of the market, probable weather conditions, counter-attractions, such as other sales, and so on. Travel conditions should be considered first of all, and the sale so timed that these conditions may in all likelihood be favorable. A breeder must be informed as to other sales, so as not to conflict with them. If possible, he should, especially if holding a yearly sale, work into a sale circuit so that his sale may become established for a certain time.

Advertising money should be spent first of all with his own breed journal, because through this medium a breeder may reach the greatest number of men interested in his particular breed. The first thing that any advertisement must do is to attract attention. This can be accomplished in a variety of ways, by playing up a certain animal, by playing up a certain farm, by carefully worded slogans, by the use of colored ink, and in many other ways that breeders and sales managers can devise, the main objects being to be brief and to the point in an attractive and sensible way.

After the breed journal should come the local dailies or weeklies, then the sectional or national publications. A list should be kept of all buyers at previous sales, as well as those in attendance, in as far as possible, and these people, together with other good prospects, circularized a month or two in advance of the sale and reminded by a post card a week previous to the day of the sale.

The breeder's two main considerations should be, first, to have a good offering in the very best of condition and, second, to do

everything in his power for the comfort and convenience of his guests. He can start taking care of his guests by seeing to it that his sale notices and advertising contain brief, clear directions regarding the location of and routes to his farm or breeding establishment. Advertising, in general, should be carefully timed and so placed as to kindle an interest which must be kept on the increase through later supplementary material, right up to the day of the sale. Advertising should tell the facts tersely and interestingly, and above all it must be strictly truthful.

FIG. 101.—An example of beef type. The Shorthorn breed furnishes splendid examples of beef type as well as claiming the worlds champion butter-fat producer Melba 15th of Darbalara, record 1614 lb. of fat in 1 year.

Advertising attempts to create or retain "good will." Three even greater influences in this endeavor are the breeder, the farm, and the animals. The animal consideration has already been discussed; the other two are equally important. The man of striking personality, who commands attention and respect because of his integrity, tolerance, and good fellowship, sells his animals much more readily and for better prices than the man who is sly, dogmatic, and exclusive. Thus selling, which is of equal importance with breeding for ultimate success, hinges quite largely on the man. Of nearly equal importance are the farm

and the home. A well-kept, attractive farm and a hospitable home are powerful aids in establishing good will and in selling.

Another phase of remunerative advertising is exhibiting at fairs. It is both desirable and necessary that breeders exhibit their stock. Show-yard winnings make excellent sales talk and the write-ups in agricultural papers of the winners at various shows constitute advertising of a most excellent kind, for which the breeder does not have to pay directly.

Cataloging.—A catalog of the sale should be prepared and sent in advance of the sale to prospective buyers. There are special-

FIG. 102.—A Red Polled cow, typical representative of dual purpose type.

ists in this field for most of the breeds, who, no doubt, can do a more efficient job than the breeder himself. As pretentious a catalog as the breeder and sale can afford should be prepared. An attractively prepared catalog, with pictures of some of the animals, three- to five-generation pedigrees of all of them, together with their records as producers and show-yard winners, is probably the very best type of advertising. Such catalogs are expensive, so that care must be used in their distribution. They should be accompanied by a carefully worded request that the recipient bring his catalog to the sale. Extreme care must be

used to see that pedigrees and statements concerning the animals are absolutely correct in every detail. If this is not done, the breeder may be accused of dishonesty, or at any rate he will have to make corrections and apologies to the crowd on the day of the sale. Such a contingency, he must avoid above all things, if he values his reputation and the success of the sale. Like his animals, on this day the breeder must have his best foot forward and see to it that he does not have to make apologies for anything.

FIG. 103.—Great Orion Sensation, a grand champion Duroc Jersey Boar 1919.

Ring or Stage Setting.—The three main considerations regarding the stage setting are convenience, comfort, and attractiveness. If the size of the sale and the crowd merit, a raised stage should be provided, which also means that the more removed seats must also be somewhat raised. From the standpoint of the animals, the selling ring must be so constructed that they may be quickly and safely led into and out of it. The floor should be covered with sawdust and an attendant in proper uniform should keep the ring free from droppings at all times. The crowd must be able to see the animals clearly without necessarily being double-jointed or cross-eyed. This point is often overlooked, though if a buyer has to sit on the edge of his

seat and "stretch" or "duck" to see what is going on, he cannot be blamed for losing interest and not bidding as enthusiastically as he might. A stage 15 to 18 feet square, somewhat raised off the ground, with a firm floor, solidly set corner posts to which rope or gas pipe may be fastened, cleated runways on either side of the raised selling box at the rear for the entrance and exit of the animals—the crowd being seated at the front and two sides—is the plan that is generally followed. If the first row of seats are

FIG. 104.—Revelation, the grand champion Percheron stallion, Eastern States Exposition 1925 owned by Mass. Agri. College.

placed close up to the ring, it will prevent the disagreeableness of people standing close to the ring and obstructing the view of those farther back.

Selling.—The selling is best handled by an experienced auctioneer of an inspiring, pleasing personality, who is acquainted with the breed and if possible with the individuals. He should be assisted by competent ring men and the breeder himself should

have things so arranged and managed in the barns that he may be able to spend his time near the ring in order to supply additional information demanded by buyers, though in such a position the owner should carefully guard his conduct. He should look pleased no matter how he feels, and above all things avoid grumpiness in speech, manner, or facial expression. He should remain in the background unless called upon and not be continually adding a word about the animals for the purpose of attempting to boost the price a few dollars. The sale should start on scheduled time and the first offering be neither the best nor the worst animal, but a little better than the average animal and of pleasing appearance and unquestioned worth. No animal should remain in the ring too long a time. If the breeder has done his work well, a competent auctioneer can soon get the price up near the upper limit which it will reach on that day; then the sale should be closed, the animal led out, and another one led in at the same time. As soon as a sale is closed the clerk must approach the buyer, inquire his name and address, and then make out two bills of the sale, with buyer's name and address, animal purchased, price, and shipping directions. The buyer must sign both copies, one to be kept by the buyer and one by the seller.

Handling the Crowd.—The manner in which a crowd is treated at a sale will be reflected in the prices received for the stock. If visitors are not welcomed nor any concern shown for their comfort, they need not be expected to react very favorably at the ringside nor will they be anxious to return in future years. Visitors attending a sale are guests and should be treated accordingly. After a long ride they will want to walk around the barns and should be encouraged to do so, all preparations having been completed before they arrive so that they cannot possibly be in the way. Buyers should be encouraged to inspect the animals before the sale starts. If the animals are numbered and the buyer has a catalog, many sales will be made before the opening word of the auctioneer, price often being a secondary consideration when a purchaser has set his heart upon owning a certain animal. Comfort stations and drinking water should be readily accessible. Probably the most satisfactory way to handle the question of eating is for the breeder to provide a box lunch. This keeps the crowd together and keeps them thinking and talking "livestock."

Integrity and Courtesy.—In the successful selling of high-class livestock there are two outstanding requirements on the part of the seller, namely, integrity and courtesy. Like every other business, that of livestock breeding contains some men who hesitate at no duplicity in order to accomplish their ends. Their number in the breeding industry is, however, nor large and from time to time as one is discovered he is ejected from his particular breed association and barred from all others. The breed associations are built solely upon the integrity of their members and the number, size, and stability of these associations is a remarkable tribute to the character of the men engaged in the business of animal breeding.

APPENDIX A

BIOMETRY

Biometry is the statistical study of variation of living things. It has been developed and is utilized to secure a numerical expression of differences and resemblances and to make comparisons of the results obtained. Biometry deals with variations, the kind of variations being of prime importance. There are two kinds which may approximate the normal variability curve, namely, those due to recombinations of genetic factors and those due to environmental stimuli. If it is intended to study the workings of inherited characteristics it will be essential to have very uniform external conditions, while if it is desired to study environmental effects it will be essential to have a pure line which is not varying because of recombinations of genetic factors. It is necessary to use extreme care in the selection of material for biometrical study.

Statistical Regularity.—The employment of the biometrical method makes it necessary to measure, weigh, or make other arbitrary classifications of the material at hand, to compute the results, and from them to draw general conclusions. It is possible to do this because of the Law of Statistical Regularity, namely, that a reasonably large amount of data picked at random from the mass, with no influences at work tending to make the choice vary in any specific direction, will give a sample, the average of which will be almost identical with the average of the whole; or, as stated by Weld:

> If a number of different events are equally possible as regards constant conditions (that is, if there is no persistent reason why one should occur rather than another), and all are repeatedly given opportunity to occur, they will in the long run occur with equal average frequency.

Or, as stated by King:

> A moderately large number of items chosen at random from among a very large group are almost sure, on the average, to have the characteristics of the large group.

Normal Curve.—Biometry is based upon the fluctuation as found in a normal curve. The normal curve is gotten by expanding the binomial $a + b$, where a equals b equals 1 and n is indefinitely large. Expanding the binomal results in the following:

$$(a + b) = 1 + 1$$
$$(a + b)^2 = 1 + 2 + 1$$
$$(a + b)^3 = 1 + 3 + 3 + 1$$
$$(a + b)^4 = 1 + 4 + 6 + 4 + 1$$

and so on. This assumes that all causes of variation are of equal value. Many biological frequency polygons simulate the normal

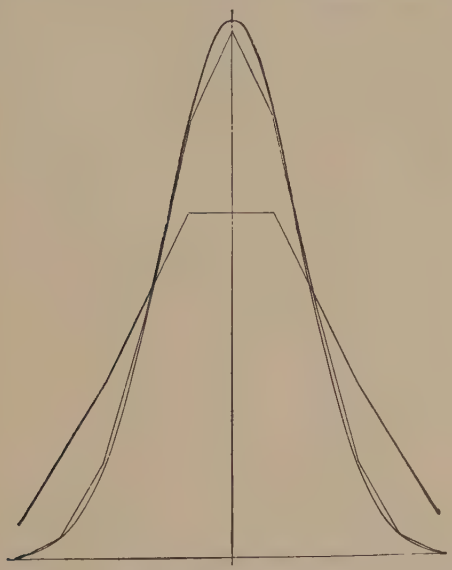


FIG. 105.—Polygons representing expansion of the binominals $(a + b)^5$ and $(a + b)^{10}$ as compared with the normal curve. (*From Genetics in relation to agriculture. Babcock and Clausen.*)

curve, while others contain unequal causes of variation and are for this reason skew polygons, the mode being rather far removed from the mean.

An examination of Fig. 105 shows that as n becomes greater there is an increasing tendency for the straight lines to blend into the normal curve.

The normal curve is perfectly symmetrical because it is made up of an indefinitely large number of individuals.

Biometrical Measures.—Through biometry is sought a group measure of type and a group measure of amount of variation from type. A biometrician uses six constants in his work, three as measures of type and three as measures of variation.

Measures of type:

1. Median.
2. Mode.
3. Mean.

Measures of variation:

1. Range.
2. Quartile.
3. Standard deviation.

As far as a normal curve is concerned, there are certain definite relationships between these constants. The mean is, of course,

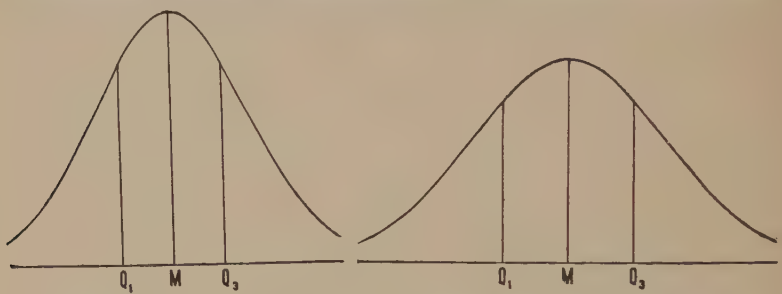


FIG. 106.—Two normal curves enclosing the same area but differing in the value of Q as well as in range.

the mean or average of all the variates, the mode is the class of greatest frequency, and the median is a perpendicular to the base erected at such a point that the area enclosed by the curve will be divided exactly in half. In a normal frequency curve these three measures of type all coincide. The mean is the measure of type most frequently used.

Of the three measures of variation, the standard deviation is the one generally used. The method of its calculation will be given presently. The range is also a measure of variation, for if the curve enclosed the same area but was more flat, the range, therefore the deviation, would be greater. The quartile is the distance from the median to a point on the base in either direction where, if a perpendicular were erected, the area, enclosed by the base, one-half the curve, and the median, would be divided exactly in half. Again, if the curve enclosed the same area but was

more flat, the distance to Q, or the quartile, would be greater, hence the quartile is also a measure of variation. Figure 106 shows normal curves enclosing same area.

The Frequency Table.—In grouping variates into classes in the frequency table it is essential that the classes be of equal range. If each class represents a range, the calculations are usually based on the centers of the class intervals. If, for example, a carload of twenty steers have been fed on a certain ration for 150 days and two of them gained between 280 and 290 pounds, five between 290 and 300 pounds, seven between 300 and 310 pounds; four between 310 and 320 pounds; and two between 320 and 330 pounds, they could be arranged in the following fashion in a frequency table:

TABLE XLVIII.—FREQUENCY TABLE

VALUE	FREQUENCY
280–290	2
290–300	5
300–310	7
310–320	4
320–330	2
	20 = N, or number of variates

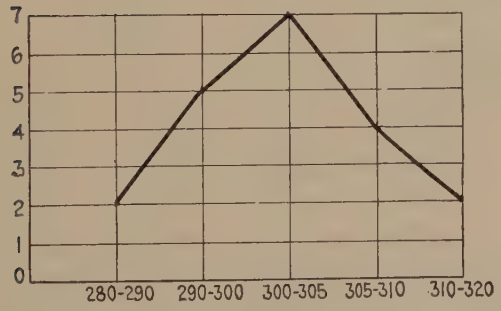


FIG. 107.—Frequency graph of gains made by steers.

The Frequency Graph.—Graphically, these data are represented in Fig. 107.

The class intervals are indicated on the base line on coördinate paper and the frequencies on the perpendicular. Since this represents the actual data, straight lines, not curves, must be used to connect the points.

Mean.—The mean may be computed by multiplying the values by the frequencies and dividing by n.

TABLE XLIX.—TO COMPUTE MEAN BY LONG METHOD

VALUE			FREQUENCY
280–290 (285)	×	2	570
290–300 (295)	×	5	1,475
300–310 (305)	×	7	2,135
310–320 (315)	×	4	1,260
320–330 (325)	×	2	650
			20)6,090(304.5
			60
			90
			80
			100

In order to obviate the necessity of multiplying the values by the frequencies which is very unwieldy where large numbers are concerned, the short method has been devised. In this a mean is assumed or guessed and a correction factor secured after the following fashion: The values and frequencies are listed as usual, then a mean is assumed and the deviation of each class from this assumed mean is listed and the product of the deviation times the frequency secured. In this case it will be guessed or assumed that the mean is 305 pounds.

TABLE L.—TO COMPUTE MEAN BY SHORT METHOD

V VALUE	*F* FREQUENCY	*D* DIFF. *V-G.*	F. D.	
280–290 (285)	2	−20	−40	
290–300 (295)	5	−10	−50	−90
300–310 (305)	7	0		
310–320 (315)	4	10	+40	
320–330 (325)	2	20	+40	+80
			20) −10	(−0.5

Column F. D. is then added algebraically and the result divided by n. This is the correction factor which must be added to G to give the correct mean. In this case the correction factor is -0.5 and, since the guess or assumed mean was 305, the true mean is $305 + (-0.5) = 304.5$. The formula for finding the mean by the short method is, therefore, $M = G + w$. It will be seen that the size of the correction factor will always be in proportion to the accuracy of the assumed mean, *i.e.*, the closer the guess the smaller the correction factor and *vice versa*—in other words, the accuracy of the guess is not important; the correction factor will always correct. Since the mean takes all individual variates into account, it is the best measure of type.

Standard Deviation.—The standard deviation is preferred as a measure of variation because in its calculation all the variates

are squared, thus giving added weight to the extreme variations, which is desirable in biometrical work. Its method of calculation (by the short method) follows along from that already completed in securing the mean. As previously stated, the deviations of each class are squared, each is multiplied by its corresponding frequency, the products are summated, this result divided by n, the square of the correction factor deducted, and the square root extracted. The formula is, therefore:

$$\sigma = \sqrt{\frac{\Sigma F \cdot D^2}{n} - w^2}$$

TABLE LI.—TO COMPUTE STANDARD DEVIATION BY SHORT METHOD

V	*F*	*D*	*F. D.*	*F. D.*^{2}
280–290	2	−20	−40	800
290–300	5	−10	−50	500
300–310	7	0		
310–320	4	10	40	400
320–330	2	20	40	800
	$n = 20$		$20) -10(-0.5 = w$	$20)2{,}500)125 - 0.25 = 124.75$

$$\begin{array}{r} 20 \\ \hline 50 \\ 40 \\ \hline 100 \end{array} \qquad \sqrt{124.75} =$$

$$\sigma = 11.16$$

Coefficient of Variation.—Inasmuch as it is sometimes desired to compare gains of steers on the same ration in different years, or even to compare things measured in different units, it is necessary to have an expression which will make it possible to have a reliable measure of such variations. This is the coefficient of variation and the formula for finding it is $\frac{100\sigma}{M}$. In the case which has been under consideration the coefficient of variation is:

$$C = \frac{100 \times 11.16}{304.5} = 3.59 \text{ per cent}$$

Probable Error.—It is necessary to compute the probable error for biometrical determinations. This arises from the fact that the number of variates being dealt with is finite and the results are going to be applied to infinity. To make it more concrete, the height of all students in a given class might be computed and the result applied to the whole student population of the college. Before being justified in this, however, the probable error of the mean height found to exist in the class must be computed. Probable error is not the most probable error, because that is 0. Probable error is an arbitrary number (computed by formulas based on truths applying in a normal curve) which must be

added to or subtracted from ($\pm$) the observed value in order to get two limiting factors of which it may be said that there is an even chance that the true value lies within or without these limits. This statement is true because in a normal frequency curve the quartiles are erected at points on the base, so that with the median they divide the total area enclosed into four equal parts. The probable error for any variate in a normal curve is the quartile, there being an even chance that the variate chosen at random will fall within or without the limits of the quartiles. In a normal curve the quartile equals 0.6745 times σ, therefore, the formulas for finding the probable error of the mean, standard deviation, and coefficient of variation are, respectively, as follows:

$$E_m = \pm \frac{0.6745\sigma}{\sqrt{n}}$$

$$E_\sigma = \pm \frac{0.6745\sigma}{\sqrt{2n}}$$

$$E_c = \pm \frac{0.6745C}{\sqrt{2n}} \left[1 + 2\left(\frac{C}{100}\right)^2\right]^{\frac{1}{2}} = \pm \frac{0.6745C}{\sqrt{2n}}$$

approximately if C is not greater than 10 per cent.

Probable Error in Comparisons.—The probable error is of great significance in the comparison of two statistical results. As stated by Rietz and Smith:

> In the comparison of two statistical results, the difference between the two results compared to its probable error is of great value. In general, we may take the probable error in a difference to be the square root of the sum of the squares of the probable errors of the two results. If the difference does not exceed two or three times the probable error thus obtained, the difference may reasonably be attributed to random sampling. If the difference between the two results is as much as five to ten times the probable error the probability of such difference in random sampling is so small that we are justified in saying that the difference is significant. In fact, a difference of ten times its probable error is certainly significient in so far as there is certainty in human affairs.

TABLE LII.—SHOWING CHANCES OF TRUE VALUE LYING WITHIN VARIOUS MULTIPLES OF E

E—the chances are even	1:1
$2E$—the chances are	4.64:1
$3E$—the chances are	21:1
$4E$—the chances are	142:1
$5E$—the chances are	1,310:1
$6E$—the chances are	19,200:1

If, for example, a steer-feeding experiment has been performed to test the relative merits of two different combinations of feeds, and the initial and final weights of the animals are available, it is a simple matter to arrange each set of gains in a frequency table and to compute the means, standard deviations, and coefficients of variation, together with their probable errors, for the two rations. Supposing such calculations gave a mean of 250 pounds ± 12 for ration 1 and a mean of 220 pounds ± 9 for ration 2. Then applying the concept of Rietz and Smith above we have:

	Mean of Gains		Probable Error of Mean
Ration 1.....	250 pounds	±	12
Ration2.....	220 pounds	±	9
	30 pounds	±	15

Or if the results gave a mean of 250 pounds ± 3 for ration 1 and 220 pounds ± 4 for ration 2 we have

	Mean of Gains		Probable Error of Mean
Ration 1.....	250 pounds	±	3
Ration 2.....	220 pounds	±	4
	30 pounds	±	5

In the first comparison the difference in gains put on by the two rations is only twice its probable error—in other words, the actual difference of 30 pounds' gain between these two rations is not very significant. If the same two rations were fed again, there is a good chance that ration 2 would prove the best. In the second comparison, however, the difference in gains put on by the two rations is six times its probable error. This is certainly a significant difference and shows that ration 1 is much more efficient than ration 2 and would prove so again if these same two rations were compared.

These relationships are represented in Fig. 108. There is one mean at 220 pounds and another at 250 pounds. The point to be determined is as to whether these data belong to one bimodal curve or to two distinct curves. The size of the respective probable errors furnishes this information. If the probable errors are respectively 9 and 12, the resulting curves would be somewhat as diagramed in solid lines below—in other words,

they would form one bimodal curve, showing that the two rations were not significantly different. If, on the other hand, the probable errors were, respectively, 3 and 4, the resulting curves would be somewhat as shown in the dotted lines below —in other words, they would form two distinct curves, showing that the two rations were significantly different.

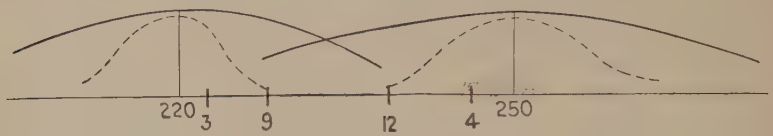


FIG. 108.—Diagram showing tendency of different gains to fall into the same or into two distinct curves as measured by the size of the probable errors.

Correlation Coefficient.—But one type of variation at a time has been considered thus far; it is often desirable to be able to deal with two types of variation simultaneously. To this end the correlation coefficient is used to show the tendency of one character to vary because another varies. A ruled table is first made up with squares as shown in the diagram below. Blocks of wood measured for length and also weighed are being dealt with in this very simple case and a correlation coefficient then derived which will show at a glance whether there is any tendency for the weight of the blocks to increase because the length increases, or whether this has no effect, or whether it tends to make them grow lighter.

On page 301 is shown one block that is 1 inch long and weighs 1 ounce, two blocks that are 2 inches long and weigh 2 ounces each, and so on, as indicated by the table. At the right is computed the mean and standard deviation for the weight in ounces (y); below is computed the mean and standard deviation for the length in inches (x). The last column at the right is the summation of the product moments of all the deviations. It must be remembered that the two deviations (from mean length and from mean weight) are being treated at the same time, hence the products of the deviations in both respects, times the frequency of their occurrence, are summated. This gives the total product-moment for all the variates in both respects. The average product-moment is then found by dividing by n, and, as the short method was used, guessing at the mean, the product of the two correction factors must be subtracted. The number so derived, divided by the product of the two standard deviations, gives the

Length in inches
$G_x = 4$

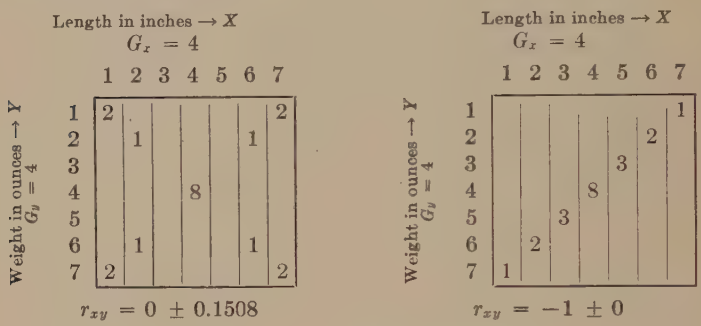
Weight in ounces → y
$G_y = 4$

	1	2	3	4	5	6	7	f_y	d_y	$f \cdot d_y$	$f \cdot d_y^2$	$\Sigma(d_x \cdot d_y)$	
1	1							1	−3	−3	9	9	−3 (−3)
2		2						2	−2	−4	8	8	−2 (−4)
3			3					3	−1	−3	3	3	−1 (−3)
4				8				8	0	0	0	0	0
5					3			3	1	3	3	3	1 (3)
6						2		2	2	4	8	8	2 (4)
7							1	1	3	3	9	9	3 (3)
f_x	1	2	3	8	3	2	1	20	$w_y = \frac{0}{20} = 0$		$\frac{40}{20} = 2$	$\frac{40}{20} = 2$	
d_x	−3	−2	−1	0	1	2	3		$w^2_y = 0$		$2 - 0 = 2$	$w_x \cdot w_y = \frac{0}{2}$	
$f \cdot d_x$	−3	−4	−3	0	3	4	3	$w_x = \frac{0}{20} = 0$ $w^2_x = 0$			$\sigma_y = \sqrt{2}$ $\sigma_y = 1.4$	$r_{xy} = \frac{2}{(1.4)(1.4)} = 1$	
$f \cdot d_x^2$	9	8	3	0	3	8	9	$\frac{40}{20} = 2$ $\sigma_x = \sqrt{2}$ $2 - 0 = 2$ $\sigma_x = 1.4$				$E_r = \pm \frac{0.6745(1 - r^2)}{\sqrt{n}}$ $= \pm \frac{0.6745(1 - 1)}{4.47} = 0$ $r_{xy} = 1 \pm 0$	

FIG. 109.—A correlation table.

correlation coefficient for which the probable error is also computed according to the formula in Fig. 109.

These data were so chosen that a perfect correlation might be secured. Now what does the correlation of 1 mean? Simply, that as the length of the blocks of wood increased by 1 inch the weight of the blocks increased by 1 ounce—in other words, this is a perfect correlation. Now if the correlation coefficients be worked out for the following two sets of data, we get the correlation coefficients shown.


Length in inches → X
$G_x = 4$
1 2 3 4 5 6 7
Weight in ounces → Y
$G_y = 4$
$r_{xy} = 0 \pm 0.1508$
Length in inches → X
$G_x = 4$
1 2 3 4 5 6 7
Weight in ounces → Y
$G_y = 4$
$r_{xy} = -1 \pm 0$

In the first case above, a zero correlation is gotten, which means that there is no tendency for the blocks to grow heavier as they grow longer. In the other case, a minus correlation is gotten, which means that as the blocks grow longer there is a tendency for them to grow lighter, in this case a perfect correlation.

The following curves should make these relationships clear.

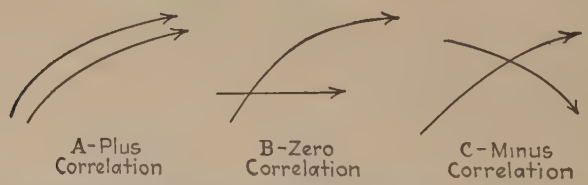


FIG. 110.—Diagram showing trends of the two variables under the three different types of correlation.

In *A* above, one thing varies because the other varies and in the same direction.

In *B* above, as one thing increases, it has no tendency to make the other increase or decrease.

In *C* above, as one thing increases, it has a tendency to make the other decrease.

This interpretation applies very well to the following data correlating the milk yield with the grain cost of producing 100 pounds of milk (Pearson of Illinois):

612 cows' records were examined
138 cows producing 5,500 pounds of milk or less:
$r = -0.348 \pm 0.050$
336 cows producing 5,500 – 8,500 pounds of milk:
$r = 0.002 \pm 0.035$
138 cows producing 8,500 pounds milk and over:
$r = +0.252 \pm 0.254$

In the first group a minus correlation, because as milk production went up the grain cost of producing milk came down.

In the second group a zero correlation or insignificantly small correlation, because as milk production increased the grain cost of producing milk remained the same.

In the third group, a plus correlation, because as milk production increased above 8,500 pounds there had to be a corresponding increase in grain fed, which made the cost also increase.

Interpretation of the Coefficient of Correlation.—King gives the following rules for the interpretation of the coefficient of correlation according to its relation to the probable error.

1. If r is less than its probable error, there is no evidence whatsoever of correlation.

2. If r is more than six times the size of its probable error, the existence of correlation is a practical certainty.

3. In cases where the probable error is relatively small:

a. If r is less than 0.3 the correlation cannot be considered at all marked.

b. If r is above 0.5 there is decided correlation.[1]

Summary on Biometry.—The measure of type is the Mean.

$$M = G + w$$

The measure of variation is the Standard Deviation.

$$\sigma = \sqrt{\frac{\Sigma F \cdot D^2}{n} - w^2}$$

For comparing different types of variation or similar types of variations in different years we use the coefficient of variation.

$$C = \frac{100\sigma}{M}$$

[1] Babcock and Clausen, Genetics in relation to agriculture, McGraw-Hill Book Company, Inc., p. 54, 1918.

Probable error must be computed because it shows how much reliance can be placed in the results secured and because the results obtained with a sample are being applied to the whole population.

Correlation coefficients may be used as a measure of heredity and also to show the tendency of one thing to vary or not to vary because another varies.

APPENDIX B

INHERITANCE IN FARM ANIMALS

Discovering and cataloging facts relative to the way in which characteristics are transmitted in farm animals have not progressed very far up to the present time. There are probably two reasons for this: (1) the fact that such research is slow, difficult work, and (2) the expense involved. In spite of this lack, breeders have greatly advanced the standard of excellence in all classes of farm livestock, though their method of trial and error has probably been, on the whole, a rather inefficient and expensive one when measured in terms of twentieth century efficiency. In the absence of specific knowledge of the mode of transmission of characters in farm animals the old adage that "like begets like" and the fact that by and large it does, has been of inestimable value to the progress of animal breeding.

Breeders will no doubt continue to use the method which they have evolved and used with such marked success, but it is to be hoped that the scope of scientific investigation of modes of inheritance in farm animals will be greatly enlarged and its efforts fruitful of results which will facilitate the production of better livestock.

It is entirely logical that the externally visible and comparatively easily measurable characteristics of animals should have been the first ones studied from the standpoint of inheritance. Even here the problem is not one of easy solution. It is slowly yielding to investigation, however, and it is to be hoped that the mode of inheritance of the deeper-lying, more complex, and more economically important characteristics, such as fertility, quality, early and economical maturity, etc., will also in time be discovered and utilized.

Color Inheritance in Mammals.—Wright has built up an hypothesis for reconciling the known biochemical facts relative to pigment production and the observed genetic behavior of color patterns in mammals. Melanin pigment is produced through the oxidation of tyrosin or related products of protein

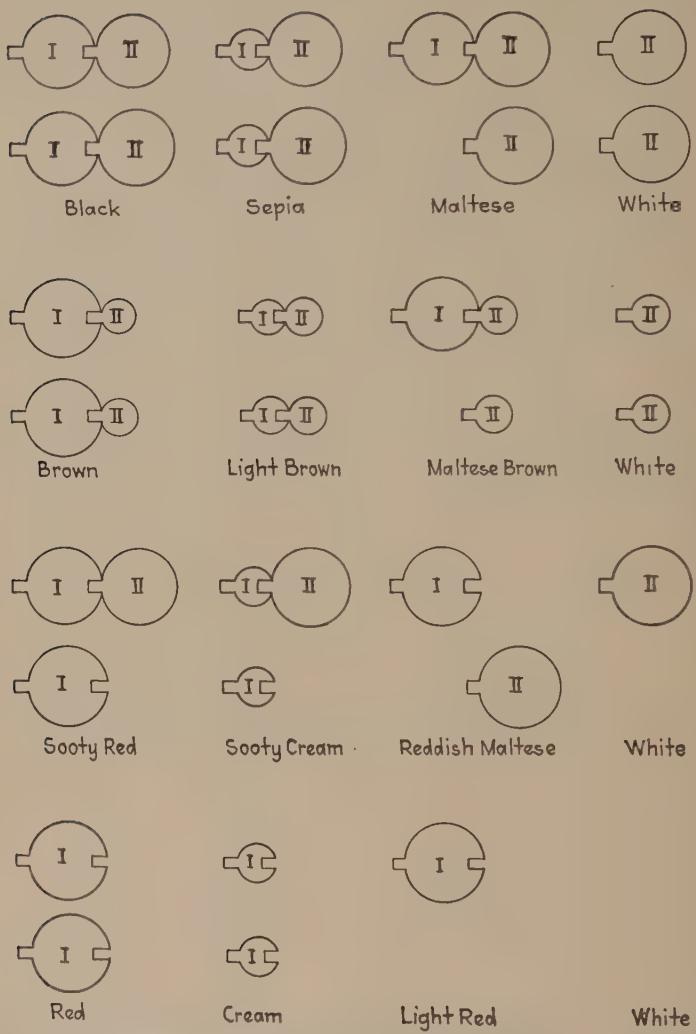


FIG. 111.—Enzymatic action in color production in Mammals. (*After Wright.*)

metabolism. The oxidation of various chromogens in the cytoplasm is probably brought about by the action of specific enzymes, probably secreted by the nucleus. As listed by Wright,[1] there are three general types of colors: (1) black and its dilution products (brown, sepia, etc.), as well as the other sort of black dilution known as roaning, where white and black hairs are interspersed; (2) red (orange, yellow tinge) and its dilution products (red human hair, red and yellow cattle, bay and chestnut horses, etc.); and (3) intergrades of various sorts between the different sepia and yellow series.

It is assumed that color depends on the rates of production or of potency of two enzymes. Enzyme I and II taken together produce black; enzyme I (essential to production of any color) by itself (II inhibited) produces red. If enzyme I is inhibited, white is produced, whether II is present or not. The diagram (Fig. 111) from Wright should make these relations clear. Full quantity is represented by two symbols, reduced quantity by a single symbol, reduced potency by a symbol of small size, and complete inhibition or impotency by absence of symbol. Variations in enzyme I are given horizontally, variations in enzyme II vertically. Hereditary differences in color are assumed to be due to hereditary differences in the enzyme element of the reaction.

The classes of color factors according to which all mammals are to be analyzed is given by Wright as follows:

1. Factors which affect distribution and intensity of color, largely irrespective of the kind of color (act as if on enzyme 1):

a. Factors which affect the distribution of color in contrast with white:

$1a_1$ white pattern (roan type) . . . . . roan cattle

$1a_2$ white pattern (piebald type) . . . . Dutch rabbit

$1a_3$ Dilution of all colors (maltese and light-red type) . . . blue rabbit)

b. Factors which affect the intensity of color in all colored areas of the skin, fur, and eyes:

1*b* Dilution of all colors (sepia and cream type, albinism), dilute guinea pig.

2. Factors which affect the distribution and intensity of the differentiation from yellow to black—effects, of course, visible only in colored areas:

a. Factors which affect the distribution of a dark color (black, sepia, brown, etc.) in contract with a yellow:

[1] WRIGHT, S., Production of coat color in mammals, *Jour. Heredity*, **8**: 230, 1917.

$2a_1$ Yellow pattern (agouti type) . . . gray rabbit
$2a_2$ Yellow pattern (tortoise type) . . tortoise guinea pig
$2a_3$ Density of black (sooty type) . . . sooty rabbit

b. Factors which affect the intensity of only the dark colors, with effects visible wherever such colors develop in skin, fur, and eyes.

2*b* Dilution of black only (brown type) . . . Brown mouse.[1]

Color inheritance in several mammals has been analyzed by Wright. We shall include his classification of the horse, cattle, and swine according to the apparent physiological effects under the scheme above.

Inheritance in Horses.—Most of the data on inheritance in horses have been gleaned from Stud books of registration. Such material is open to errors in description and interpretation as well as to those of a typographical nature. Little systematic crossing of horses with recording of data has taken place. The data on horses deal principally with coat color, which is quite generally recorded in Stud books.

Color Inheritance in Horses.—Colors in horses are more difficult to classify than in cattle or swine, because in horses there is not the uniformity that prevails in either cattle or swine. Except in the Suffolk, which must always be a chestnut, there is no hard-and-fast color specification in any breed. In all breeds are to be found most of the ordinary colors, such as black, brown, chestnut, bay, roan, and gray. For this reason, it is probably safe to say that a large percentage of horses are heterozygous for coat color and this renders the proper interpretation of data from Stud books extremely difficult.

Starting with black body color there are found various types of dilutions in the horse, including brown, dun, chestnut, bay, sorrel, and occasionally a lack of color, or white. There are two sorts of roans; (1) where the body color is black, giving a gray roan (may be alternating black and roan spots, giving a dappled gray), and (2) where red, a red roan. The mane, tail, and lower part of the legs also seem to behave as a unit, being self, black, or sorrel usually. Before proceeding to a general discussion of color in horses it will be well to review and define colors in horses.

Black.—This term needs no definition. Black is generally regarded as being recessive to all colors except chestnut. Black differs from bay by at least one factor.

[1] WRIGHT, S., Color inheritance in mammals, *Jour. Heredity*, **8** (8): 373, 1917.

Browns.—1. Seal brown is a rusty or faded black,

2. Mahogany brown (black alternating with bay), Anderson says, is really a bay.

3. A yellowish, grayish brown (usually with black mane, tail, and legs). A mouse or cream color. A dilute form of bay, black, or chestnut. A dominant characteristic.

Chestnut.—A reddish brown or dark liver color and solid. Recessive to all other colors.

	g^c	g^h	g^b	g^d	G
G	Gg^c Gray 3 gray : 1 chestnut	Gg^h Gray 3 gray : 1 black	Gg^b Gray 3 gray : 1 bay	Gg^d Gray 3 gray : 1 dun	GG Gray All gray
g^d	g^dg^c Dun 3 dun : 1 chestnut	g^dg^h Dun 3 dun : 1 black	g^dg^b Dun 3 dun : 1 bay	g^dg^{d-} Dun All dun	
g^b	g^bg^c Bay 3 bay : 1 chestnut	g^bg^h Bay 3 bay : 1 black	g^bg^b Bay All bay		
g^h	g^hg^c Black 3 black : 1 chestnut	g^hg^h Black All black			
g^c	g^cg^c Chestnut All chestnut				

FIG. 112.—The genotypes of gray, dun, bay, black and chestnut coat colors in the horse according to the formulation of Wilson. The way in which animals of a particular genotype behave in a subsequent generation when mated together is shown in each square. (*From Genetics in relation to agriculture. Babcock and Clausen.*)

Bay.—A body of bay color (light reddish chestnut) with black mane, tail, and feet. Generally considered dominant over black.

Sorrel.—A bay or chestnut body with lighter (flaxen) mane and tail. A recessive color.

Gray.—White and black hairs, each more or less grouped in patches. Usually the dappled condition, *i.e.*, black background with gray patches (almost white to almost black). May be very dark while young and turn gray with age. Gray is dominant to all colors except roan.

Roan.—Gray—gray and white hairs interspersed; blue—black and white hairs interspersed; red—bay and white hairs interspersed; chestnut—chestnut and white hairs interspersed. Roan pattern is considered to be dominant to all other patterns.

Piebald.—White with colored spots; usually heterozygous for pied.

White.—Possibly homozygous for pied.

A system of multiple allelomorphs has been proposed by J. Wilson to account for coat color in horses. He assumes gray, dun, bay, black, and chestnut to be such a series in which each color is dominant to succeeding and recessive to preceding colors. Graphically, the scheme is represented in Fig. 112.

Wilson also assumes an independent dominant factor for roan and modifying factors for the degree and distribution of pigment. Such a system of multiple allelomorphs or polygamous factor should produce a graded series of effects when arranged in the order of dominance. This is impossible in Wilson's scheme.

Table LIII, compiled by Anderson from various Stud books, gives the results of a great many types of matings.

TABLE LIII.—INHERITANCE OF COAT COLOR IN HORSES (*After Anderson*)

Mating	Chestnut	Black	Brown	Bay	Gray	Roan
Chestnut × chestnut	14,115	10	1	5		
Chestnut × black	111	83	20	124		
Chestnut × brown	60	32	31	130		
Chestnut × bay	597	56	49	764		
Black × black	11	295	15	5		
Black × brown	14	198	219	115		
Black × bay	123	295	261	634		
Brown × brown	13	64	334	157		
Bay × brown	177	132	817	1,449		
Bay × bay	474	107	300	2,831		
Roan × chestnut	9	3	2	9	1	14
Roan × black	1	11	3	1	0	15
Roan × brown	1	5	16	18	1	28
Roan × bay	9	5	13	39	1	50
Roan × gray	.....	...	3	.....	5	7
Roan × roan	.....	...	...	3	2	9
Gray × not gray	.....	Not gray	...	528	439	
Gray × gray	.....	Not gray	...	18	47	

It will be recognized that Wilson's scheme would make it impossible to secure bay or brown from a mating of black and

chestnut, as neither of these colors could carry the dominant bay factor. The table shows that such matings produced 111 chestnuts, 83 blacks, 20 browns, and 124 bays. Placing most coat colors in one series of allelomorphs is, therefore, seen to have many drawbacks.

Wright's Analysis of Color in Horses.—Wright's analysis[1] agrees, in general, with Wentworth's earlier hypothesis of many different pairs of allelomorphs which might be found in all combinations. His general classification[2] of the factors involved is as follows:

Bay Horse—*grvdMAB*	
1*a*1	*G*, *gG*—gray
	R, *rR*—roan
1*a*2	*V*, *vV*—piebald
1*a*3	
1*b*	*D*, *dD*—dun
	M,*m*—*hhmm* sorrel
2*a*1	*A*, *aA*—black
2*a*2	
2*a*3	
2*b*3	*B*, *bb*—chestnut

Under this scheme the aforementioned production of bays and browns from matings of chestnut and black is to be expected, as each parent supplies the dominant factor which the other lacks.

The behavior of certain grays (producing bays when mated with chestnuts) makes it seem likely that they are double heterozygotes *Gg Bb*. The gray stallion, Gray Friar, mated with chestnut mares produced, according to Wilson, fifteen grays, three bays, and four chestnuts. Therefore gray can transmit both bay and chestnut.

Some grays are homozygous, producing only grays when mated with mares of all colors. Others are heterozygous, producing close to the 50:50 ratio on other colors. These statements also hold for roans. Wright, therefore, places both gray and roan in class 1*a*. The relation between gray and roan is not clear.

Since self by self gives only self, and self by pied gives about half and half of pied and self offspring, it seems that pied must usually be heterozygous and dominant.

[1] Wright, S., Color inheritance in mammals, *Jour. Heredity*, 8 (12): 563, 1917.

[2] See explanation of classification on p. 307.

Bay with the associated black legs, mane, and tail seems to be due to a dominant inhibitor of black for all the parts except those just named. Bay is a simple dominant over black. Wright places the factor in class $2a_1$.

Brown is hard to classify. Anderson considers mahogany brown to be genetically bay. Seal brown is perhaps a dilution of black, most brown appears to have the bay factor.

"The factor by which chestnuts of all shades differ from blacks and bays is somewhat difficult to classify. An ordinary chestnut shows little but red and might be compared with the recessive red of guinea pigs. But liver chestnuts show a larger amount of dark pigment which, however, is brown, not black. Thus the factor may well be placed in class $2b$ with the chocolate factor of rodents. Appearances suggest that livers differ from ordinary chestnuts in the same way that blacks do from bays, *i.e.*, in having factor a in place of A, but the writer knows of no data which bear on this point.

Grades of Intensity.—There are many grades of intensity in horses, especially noticeable in chestnuts, which remain to be analyzed. A dominant general dilution factor by which buckskin duns, mouse-colored horses, and creams differ from bays, blacks, and chestnuts seems best established. Although dominant, it is put for the present in class $1b$, the factors of which it most resembles in effect. Besides this, Wentworth has shown that there is a recessive factor which is responsible for the difference between light-maned sorrels and those with dark manes, a result which has been confirmed by McCann. Light-maned, liver chestnuts which seem to have this factor are not uncommon. It may also be put in class $1b$, but so far its effect in bays and blacks has not been worked out.

Color Inheritance in Horse Hybrids.—There are a number of curious facts in connection with horse hybrids which need more investigation. Gray and piebald remain dominant in crosses between horses and asses. In a cross made by Ewart between a zebra and a piebald mare, the hybrid showed no trace of the piebald pattern, but the dam may have been a heterozygous piebald. It is often held that dun is the ancestral color of the horse, the wild Przevalski horse showing an approach to this color. Zebras also show a pale-cream ground color with black stripes and would be expected to have factor D. Nevertheless, when crossed with chestnut, black, or bay horses, the offspring approach

bay rather than dun. If the zebras contain the same factor as dun horses, dominance is reversed. Finally, another apparent reversal of dominance must apparently take place in the production of chestnut mules, as anything like this color is unknown in donkeys and factor *b* is recessive in horses."[1]

TABLE LIV.—EFFECTS OF FACTOR COMBINATIONS (*After Wright*)

	gr	*gR*	*Gr*	*GR*
DAB.....	Dun	Dun roan	Gray	Gray (born roan)
DaB.....	Mouse	Mouse roan	Gray	Gray (born roan)
DAb.....	Cream	Cream roan	Gray	Gray (born roan)
Dab.....	Cream	Cream roan	Gray	Gray (born roan)
dAB.....	Bay	Bay roan	Gray	Gray (born roan)
daB.....	Black	Blue roan	Gray	Gray (born roan)
*dA*b.....	Chestnut	Strawberry roan	Gray	Gray (born roan)
dab.....	Chestnut (liver)	Strawberry roan	Gray	Gray (born roan)

Inheritance of Other Characteristics in Horses.—There is little definite knowledge of inheritance of characteristic other than color in horses.

Hurst lists the following contrasted characters as allelomorphic: concave and convex faces; straight and curved thighs and hocks; prick-ear, drooping ear, forward droop and outward droop of ears; sprinters and stayers; liability to cataract blindness, breaking blood vessels and paralytic roaring (contrasted with normal conditions); long back and short back. The natural trotting gait appears to be a simple dominant to pacing, although there is still considerable doubt as to these characters.[2]

Color Inheritance in Cattle.—Attempts have been made to work out the color reaction of Shorthorn cattle on a two-factor hypothesis. Under this scheme homozygous self-red is *RR pp*, homozygous white *rr PP*, and a mating of these produces a roan *Rr Pp* (some roans of *RR Pp* and *Rr PP* constitution are also known).

[1] WRIGHT, S., Color inheritance in mammals, *Jour. Heredity*, 8: 563, 564, 1917.

[2] BABCOCK and CLAUSEN, Genetics in relation to agriculture, McGraw-Hill Book Company, Inc., p. 465, 1918.

The factor groupings in such a system would be as follows:

	PP	*Pp*	*pp*
RR	Roan	Roan	Red
Rr	Roan	Roan	Red
rr	White	White	White

Under this scheme red to red or red and white, or red and white to red and white, should not produce roans and neither should white to white.

The results of various matings as reported by Wentworth were as follows:[1]

TABLE LV.—RESULT OF MATINGS IN SHORTHORNS (*From Wentworth*)

	Red	Red and white	Roan	White
R × *R*	1,180	115	68	16
R × *R* and *W*	223	119	23	22
R × roan	1,431	217	1,212	13
R × *W*	6	9	667	17
Roan × *R* and *W*	62	53	124	2
Roan × roan	459	205	1,275	471
Roan × *W*	3	5	168	72
R and *W* × *R* and *W*	21	52	11	1
R and *W* × *W*	3	2	224	1
W × *W*	4	0	8	141
Totals	3,392	777	3,780	755

Allowing for certain erroneous and fraudulent registrations (red and whites being unpopular and recorded as roans), this scheme accounts fairly well for all the colors produced by the stated matings that were analyzed. This is in contrast to the theory of Wilson that roan is a simple heterozygous mixture of red and white.

Wright's Analysis of Color in Cattle.—Wright has rearranged the table from Wentworth on Shorthorn cattle by combining the red and whites and reds as follows:

[1] WENTWORTH, E. N., Color in Shorthorn cattle, *Amer. Breeders' Mag.*, **4** (4): 202–208, 1913.

TABLE LVI.—COLOR COMBINATIONS IN SHORTHORN CATTLE (*From Wright*)

	Red	Roan	White	Total	Expected
Red × red	1,710	102	39	1,851	1,998
Red × roan	1,763	1,336	15	3,114	3,620
Red × white	20	891	18	929	724
Roan × roan	664	1,275	471	2,410	1,642
Roan × white	8	168	72	248	657
White × white	4	8	141	153	64
	4,169	3,780	756	8,705	8,705
	47.9 per cent	43.4 per cent	8.7 per cent		

"The last column gives the expected number of young from each kind of mating on the basis of unit factor inheritance if matings were wholly random as regards color,"[1] provided also that the Shorthorn population is in equilibrium as regards color. The expected number of red by red matings should be 0.479 × 0.479 per cent of the total (8,705), or 1,998.

Since white (*rr*) is 8.7 per cent and the heterozygotes must be twice the product of the square roots of the number of the two homozygous classes, then heterozygous colored (*Rr*) is 41.6 per cent and homozygous colored (*RR*) 49.7 per cent. Disregarding white, where the distinction between roan and red is considered to be hidden, the percentage of homozygous roan (*PP*) is found to be 7.6 per cent, of heterozygous roan (*Pp*) 40.0 per cent, and of red (*pp*) 52.4 per cent. These figures give the following table:

TABLE LVII.—PERCENTAGE FACTOR COMBINATIONS (*From Wright*)

	PP	*Pp*	*pp*	
RR	3.8	19.9	26.1	49.8
Rr	3.2	16.6	21.8	41.6
rr	0.7	3.5	4.6	8.8
	7.7	40.0	52.5	100.2

By means of this table Wright has calculated the expected percentage (on random mating) from red by white and roan by roan parents for the two-factor hypothesis. These per cents, those

[1] WRIGHT, S., Color inheritance in mammals, *Jour. Heredity*, 8 (11): 521–522, 1917.

expected on the one-factor hypothesis, and those actually found comprise the following table, which lends strong support to the one-factor hypothesis without dominance.

TABLE LVIII.—TABLE OF EXPECTATIONS IN SHORTHORNS (*From Wright*)

Parents red × white	Per cent red	Per cent roan	Per cent white
By two-factor hypothesis	55.9	21.3	22.8
By one-factor hypothesis	0.0	100.0	0.0
Actually found	2.2	95.9	1.9
Parents roan × roan			
By two-factor hypothesis	16.7	78.1	5.2
By one-factor hypothesis	25.0	50.0	25.0
Actually found	26.6	52.9	19.5

It is also to be observed that since there are 756 whites (*WW*) and 4,169 reds (*ww*) there should be, on the one-factor hypothesis and on random mating twice the square root of the product or 3,551 roans. There were 3,780 roans, which is a very close agreement, considering the probable departures from random mating.

Wright suggests that the discrepancies found above may be due to herd book errors or to the fact that there are three different kinds of white in cattle, *i.e.*, the dominant white of the Chillinghams cattle, the recessive white of the Pembroke or Highland cattle, and the neither dominant or recessive white of the Shorthorn. These whites might be due to a series of allelomorphs, where "a more potent white factor is dominant over a self-factor which is just below the roan level, *or vice versa*" or to a single Mendelian pair (cooperating with lesser factors) with "a continuous series of physiological conditions between a very strong self-tendency through roan to a very strong white tendency with color in any given area due to both hereditary and developmental (making it possible for adjacent hairs to have different potencies and so produce the roan effect) factors. Data for testing the two theories are lacking."[1]

Wilson postulates a series of allelomorphs for black, red, and white in cattle according to the following plan:

[1] WRIGHT, S., Color inheritance in mammals, *Jour. Heredity*, 8: 523, 1917.

BB—black		
BR—black	*RR*—red	
BW—blue roan	*RW*—red roan	*WW*—white

As Wright suggests, it would be impossible to get reds from blue roans (*BW*) on Wilson's hypothesis, but entirely possible to get them from his hypothesis of independence (*Ee Ww*), as indicated in his classes and factor combinations as follows:

BLACK COW—*wvdmE*

$1a_1$ *W*, *w Ww*—roan, *WW*—white
$1a_2$ *V*, *vV*—pied
$1a_3$
1*b* *D*, *dD*—dun
M, *m ee MM*—mahogany (sex limited)
$2a_1$
$2a_2$ *E*, *e ee*—red
$2a_3$—Unanalyzed factors for brindle
2*b*

FACTOR COMBINATIONS

	ww	*Ww*	*WW*
DE	Dun	Dun roan	White (dun ears)
Dee	Yellow	Yellow roan	White (yellow ears)
ddE	Black	Blue roan	White (black ears)
dd ee	Red	Red roan	White (red ears)

As a matter of fact, Lloyd-Jones and Evvard got six reds (from solid reds, one red and white, one red roan) out of twenty-six F_2 calves from white and red roan Shorthorns mated with Galloways.

The pied characteristics (white and black or some other color) varies in amimals, from one with a very small amount of white, perhaps on switch or underline, to one practically entirely white except for eyes. It includes combinations as found in Herefords, Dutch Belted, Ayrshires, Holsteins etc. There is little established regarding its mode of inheritance. It is probably "heterozygous intermediate with much variation which is not genetic."[1] In guinea pigs various types of pied patterns "may crop out even in the same litter in a stock in which the total amount of white is relatively constant" and MacCurdy and Castle have shown "that a tendency toward one type of pattern can be produced by selection."[1]

[1] WRIGHT, S., Color inheritance in mammals, *Jour. Heredity*, 8:526, 1917.

The conditions strongly suggest that the pattern is the resultant of two very different kinds of factors, factors which determine a certain general level of some essential for pigment production and factors which affect the course of development so as to bring out particular lines of weakness in which the pattern of white shall appear if the general level is low enough. On this view a Hereford, a Dutch Belted cow, and a Holstein might possess the identical piebald factor as regards quantity but differ in hereditary factors which determine the type of regional differentiation. As far as the writer knows, no Mendelian differences of this second kind yet have been demonstrated in any mammal.[1]

Red in cattle has been shown to be a simple recessive to black. This explains how red calves can logically be produced in Angus and Galloway herds.

Wright classified the brindles, duns, and dark mahogany browns as intergrades between red or yellow and black. Brindle is the appearance of irregular streaks of black or red, yellow, dun, or black and is not a popular color in the United States. It probably is due to unanalyzed factors of class $2a_3$.

More definite conclusions can be reached in regard to dun. The following table, which is a slight modification of Wilson's table for herd book 2 of the Highland cattle, shows some very interesting points. The progeny of each color are tabulated by per cent of the total, the total numbers being given in the last column for reference.

TABLE LIX.—COLOR COMBINATIONS IN HIGHLAND CATTLE (*From Wright*)

		Black	Dun	Red	Yellow	Brindle	Number
Black	× black.....	71	5	18	1	5	97
	× dun.....	29	45	11	13	1	82
	× red.....	43	4	43	4	7	239
	× yellow.....	27	24	16	29	3	74
	× brindle.....	45	2	29	2	22	181
Dun	× dun.....	(6)	0	0	(6)	(88)	(16)
	× red.....	18	13	23	46	0	54
	× yellow.....	2	53	11	30	5	64
	× brindle.....	18	32	9	18	22	87
Red	× red.....	3	1	86	9	2	131
	× yellow.....	5	2	46	35	12	121
	× brindle.....	4	0	67	6	23	188
Yellow	× yellow.....	5	2	46	35	12	73
	× brindle.....	3	4	22	49	23	111
Brindle	× brindle.....	13	0	35	2	50	80

[1] Wright, S., Color inheritance in mammals, *Jour. Heredity*, **8**: 526, 1917.

A consideration of this table certainly justifies Wilson's contention that duns contain the factor by which blacks differ from reds. The crosses involving only red, yellow, and brindle produce very few blacks and duns, probably no more than can be accounted for by errors in the records. The cross of black with black produces 71 per cent blacks, not much below the 75 per cent expected if blacks are heterozygous (*Ee*), which should generally be the case in Highland cattle. Black by red or brindle produces but little less than the expected 50 per cent. But in the crosses of black by dun or yellow only 29 and 27 per cent black calves are produced, which shows clearly that factor *E* must be present in some other color than black. This color can only be dun (except perhaps for an occasional black brindle). Combining blacks and duns as mostly of formula *Ee*, and reds, yellow, and brindles as mostly *ee*, the agreement between figures and expectation becomes fairly good.

It is further evident from the table that dun and yellow are closely related in some way. Black by yellow produces many duns (24 per cent) and dun by red produces many yellows (46 per cent), while neither color is produced in reliable numbers unless at least one parent is either dun or yellow. Wilson explains this by assuming that dun and yellow are respectively the heterozygotes of black and red with the rather uncommon cream-colored light dun which he puts in the same series as black and red. As an alternative hypothesis we may suppose that dun and yellow differ from black and red respectively by an independent dominant dilution factor of class 1*b*.

1. Triple Allelomorphs

BB black
BR black, *RR* red
BL dun, *RL* yellow, *LL* light dun

2. Two-factor Hypothesis

	DD	*Dd*	*dd*
EE	Cream dun	Dun	Black
Ee	Cream dun	Dun	Black
ee	Cream (light dun)	Yellow	Red

Probably the best criterion between the two hypotheses which is present in the data is in the results of the cross dun by red. On Wilson's view (1), this should produce only blacks and yellows $BL \times RR = BR + RL$. On hypothesis (2), duns, blacks, yellows, and reds should all be produced ($Ee\ Dd \times ee\ dd = Ee\ Dd + Ee\ dd + ee\ Dd + ee\ dd$). The results, seven duns, ten blacks, twenty-five yellows, and twelve reds, point strongly toward the hypothesis of independence, although

the excess of yellows and reds indicates that some of the parents called duns were probably really yellow lacking factor *E*. The color called light dun appears generally to be extreme dilution of red. It produces very few blacks and duns unless crossed with these varieties. The evidence for a unit Mendelian difference between red and light dun with yellow as the heterozygote is not so clear cut as could be wished, but the same considerations which apply in the case of roan Shorthorns apply here. Yellow by yellow seems to produce distinctly fewer yellows than does red by light dun. No doubt, subsidiary factors must be assumed to produce overlapping of class ranges. Following are some figures given by Wilson. The yellow by yellow data are from herd books 13, 14, 15; the red by light dun from books 3 and 15.

	Red	Brindle	Yellow	Light dun	Dun	Black
Yellow × yellow	15	5	40	8	5	1
Red × light dun	4	0	25	3	1	1

The factor *D* by which dun and yellow differ from black and red respectively fits best into class 1*b* and may be compared with the dun factor of horses. Dun cattle, it is true, appear to differ from blacks not only by dilution of color but by increase in yellow, but even blacks often show a red rustiness at the tip of the hair, which suggests that they have been selected from a type with a pattern comparable to the agouti of rodents. In the general dilution of color brought about by factor *D*, the reduction in density of black permits the agouti pattern to become more visible. There is probably no color in cattle which can be compared with the recessive black among rodents. The blacks in cattle find their best homologue in the gray mice blackened by the black-and-tan factor, or in the black rabbits due to the addition of Punnett's density factor to grays.

Whether the colors which appear similar in the different breeds of cattle are really so genetically could only be determined by careful experiments. Judging by appearances it is probable that the dun dilution factor of Highland cattle is found also in the Guernseys and Jerseys. The former appear to be *ee DD* and most of the latter *EE DD*. Kuhlman reports on the cross of Jersey with black Angus. F_1 was black or very dark tan. In F_2 black, dark dun, and orange fawn appeared. The general level of intensity appears to be higher here than in Highland cattle.

Probably there are variations in intensity which do not belong to the series discussed. Wentworth has reported on a very interesting

factor in the dark mahogany-colored Ayrshires. He finds clear evidence of sex-limited inheritance. Heterozygous males are dark colored while heterozygous females are like ordinary reds.[1]

Duck's Analysis of Color in Shorthorn Cattle.—Duck has worked out a system to account for the various types of colors found among Shorthorn cattle. His work is based on the tabulated pedigrees of part of the animals registered in the herd book for 1921. Some 10,000 animals were studied. As Duck points out, there is considerable opportunity for error in Shorthorns because red-and-white animals may be registered as red and an animal with any roaning is apt to be recorded as roan, though for the most part it may be red and white. Duck considers roan and red and white as essentially the same genetically.

Table LX will illustrate the essential points of the system:

TABLE LX.—DUCK'S FACTOR COMBINATIONS IN SHORTHORNS

	EE	*Ee*	*ee*
RR	Red	Red	Red
Rr	Roan	Roan (or red and white)	Red and white
rr	White	White	White

In the above *R* is the basic color of Shorthorn, namely, red while *r* is the absence of red or white. As will be seen, roan (or red and white) is the heterozygous condition between red and white. In other words, this is essentially a two-factor system with an extension factor *E* which determines the amount of extension of red color among the white. As roans do not occur from mating black on black but do occur from mating white on black, it is logical to assume the factor *E* is associated with white in Shorthorns. The appearance of red calves from a red-on-white mating is explainable on the assumption that the white parent was heterozygous for the factor *E*.

That the red of the Shorthorn can also carry the roan extension factor is unquestionably proved by the results obtained from the various matings. The question logically arises, Why will a cross between red and black produce no roans? The reason is apparent when it is con-

[1] WRIGHT, S., Color inheritance in mammals, *Jour. Heredity*, 8: 526–527, 1917.

sidered that red and black are genetically, as well as practically, true allelomorphs, resulting in complete dominance of black in the heterozygote, which, in turn, will separate out in the second generation in the definite Mendelian ratio of three dominants to one recessive. This has been proved too often to need further discussion. It will serve, though, to show that the red of the Shorthorn may be often associated with the roan extension factor *E*, but its presence will not be proved, as it will not be brought to light in the phenotype.

Many of the apparent contradictions which occur in the various color matings of Shorthorns can be eliminated if it is assumed that red and white in the Shorthorns is not caused by the introduction of an extension factor entirely different from roan *E*, but is really produced by the total absence of *E* and can be represented as *e*. When this occurs in the presence of a heterozygous condition for red *R*, a red-and-white animal is produced . . .

Apparent Contradictions Explained.—Apparent contradictions are not so great as would seem at first glance . . . It is obvious that the greatest source of error is the registration of red individuals. The recording of 12 per cent red and white, 3 per cent roan, and 1 per cent white from this mating is sufficiently close to the theoretical possibilities to be within the limits of probable error. One or both the parents in these cases must have been genotypically red and white, but the pattern in the phenotype showed so great a preponderance of red that the individual was recorded as a red.

The appearance of such individuals as Rosewood Radium, which shows a phenotype carrying both roan and pied pattern, can be explained by assuming they have a genetic make-up of *Rr Ee*, with respect to the colors in question . . . Theoretically, a true red and white *Rr ee* . . . crossed on *Rr ee* cows will produce no roans. Actually between 5 and 10 per cent roans are recorded as resulting from matings of red and white on red and white. This is possible, when it is considered that animals having the zygotic formula *Rr Ee* may be recorded as red and white. Matings of *Rr Ee* and *Rr ee* would allow theoretical possibilities of 25 per cent roans . . . It would seem unlikely that *Rr ee* and *Rr Ee* would occur in equal ratio. In fact, the preponderance of data shows that whenever possible *Rr Ee* individuals are registered as roans because of the greater popularity of this color over red and white.[1]

Smith's Analysis of Color Inheritance in Shorthorn Cattle.—Smith has critically examined the evidence in support of the one- and two-factor hypothesis. He points out the following shortcomings of the two-factor hypothesis of Wentworth (*R* = red, *r* = white, and *P* = roan): "It implies the production of white

[1] Duck, R. W., Shorthorn color inheritance, *Jour. Heredity*, **14**: 69–72, 1923.

animals in which the roaning factor is absent . . . a white which, when mated to reds, gave solely red or white." Regarding Duck's dihybrid theory (R = red, r = white, and E = roan, which can act only on the heterozygote Rr) the above criticism also holds together with the fact that Duck's theory makes it necessary to assume that three out of four reds carry the roan factor. Smith says further:

> The fact that reds, including red and whites, when mated together give only 5.9 per cent roans by no means goes to prove that reds carry a latent roan factor. It is, rather, pretty useful proof that they do not. The explanation as to why the red and white mated to reds gave 20 per cent roan according to Duck's figures is not hard to seek when it is remembered that, as a great many reds which have a little white are registered as red (particularly in America), it is chiefly those reds which have considerable white which are registered as red and white. It is possible that not a few red-and-white parents in the red by red-and-white matings could have been roan and have given rise to roan, while not a few of the roan offspring may have really been red and white.
>
> Furthermore, reds mated to what Duck admits is their allelomorphic color, black, have never been known to give either roans or blue greys. Duck explains this by saying that black is completely dominant in the heterozygote, ignoring the well-established fact that a Galloway black with a Shorthorn roan gives rise to about 50 per cent black and 50 per cent blue gray, and with a white Shorthorn, which is usually more "prepotent" for the roaning factor (*i.e.*, homozygous, according to the monohybrid theory), gives 100 per cent blue gray. Roans homozygous for the roaning factor, *Rr EE*, do not appear to exist, yet this hypothesis demands their appearance. Thus, while some of Duck's figures appear to fit the facts rather better than the monohybrid, others are no improvement upon it. Those that do can in every case be easily explained by the doubtful division line which exists between roan and red and white.
>
> An equally serious objection is that in other breeds the colored and white breed true. Nowhere else in the cattle world does spotting appear to be heterozygous. It has been clearly shown that it is a recessive condition by Kuiper, Plank, and Durham. Moreover Duck, in his paper, makes some rather sweeping, if not illogical, statements, such as that the black of the Galloway "acts differently than the red of the Shorthorn towards assuming a pied pattern in the phenotype," due to the presence of some inhibiting factor which acts only in the presence of the black, though in the next sentence he is careful to point out that black and red are allelomorphic. While this is vaguely possible, it is improbable, especially where the roan factor is taken rather as altering the type of the spotting than as scattering red or white hairs throughout

a pigmented coat. Another statement to the effect that roan by white will give more roan than will roan by red must, although supported by the figures in the table, be treated with reserve in view of the fact that there is a distinct prejudice amongst many breeders against registering white calves unless they show promise of becoming good individuals.

Thus this theory breaks down in a good many more points than the simpler monohybrid. Although certain aspects are plausible, taken as a whole, and especially in relation to facts demonstrated in cattle outside the Shorthorn breed, the theory is reared on premises that are none too sound.

Smith considers that since "there are amongst roan shorthorns many of uneven roaning which show distinct white patches coming through the roan" that this spottedness may be inherited more or less independently of the roan factor or factors and, further, that the spots occurring in the red and white would equally well occur in the roan. Smith adduces evidence which tends to substantiate the theory that the self-condition is dominant to pied.

It would therefore seem logical to assume that there is acting in the Shorthorn breed the same factor which in its recessive form causes the pied condition in other breeds. This factor probably seldom reaches quite the same degree of lack of pigmented areas as sometimes occurs in the Holsteins because it is severely discriminated against, spotted reds and roans being looked upon with disfavor by the Shorthorn breeders. That this factor is recessive has been clearly shown by the results of others. Further proof that this is the case may be found in the fact that, although for many years the solid red and very even roan have been by a long way the favorite colors, they are by no means always the most common at the present day. Had the pied been dominant, the breeders could have eliminated the spotted beasts with comparative celerity.

Some blue roans are supposed to breed true, but Smith adduces evidence which refutes this idea. The other objection to the monohybrid theory is the production of a large number of reds from certain matings of white bulls and red cows. Upon investigation Smith concludes that these reds should be recorded as roans, "for there is a tendency amongst white bulls to throw roan calves which appear almost red," the roaning being more prominent at birth and the animals usually being registered as roans.

Thus considerable doubt is cast on the validity of the two objections to the monohybrid theory. Since it is the simplest and adequately

explains the general trend of facts, it would appear wise to adopt it as a working hypothesis. This, coupled with the hypothesis that spotting is a recessive condition (excluding in cattle, generally, the dominant markings of the head, belt, and, perhaps, "inguinal spot") would give a fairly simple explanation that could be readily understood by the average breeder.

If, then, it be assumed that R = red color (incomplete dominance) and its allelomorph r = white, the heterozygote Rr being roan, S = self-color (dominant) and its allelomorph s = pied, then the various types of the Shorthorn coat color may be represented as in Table LXI.

TABLE LXI.—SHORTHORN COAT COLOR, PHENOTYPES, AND GENOTYPES (*From Smith*)

Type	Description	Phenotype	Genotype
Red.....	Self or solid color with perhaps an "inguinal spot"	*RRS*	*RR SS* or *RR Ss*
Red and white..	Distinct white underline at least	*RRs*	*RR ss*
Roan (even)....	An even mosaic of any intensity	*RrS*	*Rr SS* or *Rr Ss*
Roan (uneven)..	Of any intensity but spotted	*Rrs*	*Rr ss*
White.....	With dark eyes and some pigmented hairs in the ears	*rr*	*rr SS* or *rr Ss* or *rr ss*

There will be, of course, the interaction of many subsidiary genes modifying each type to a considerable extent. Thus the action of the "inguinal spot" dominant factor may cause a considerable number of reds of the phenotype *RRS* to appear as red and white, *RRs*. The action of factors on the roan may so darken the coat color and modify it as to cause the phenotype *RrS* to appear as a red *RRS*, or, even more likely, to cause *Rrs* to appear as a red and white, *RRs*. The same or similar factors acting in the opposite direction might make the light roan of phenotypes *RrS* and *Rrs* appear as white *rrS* or *rrs*. Some white bulls mated to spotted cows would give only spotted offspring.

How to Breed the "Solid Red" and the "Even Roan."—In order, therefore, to obtain the "nice even roan" it would be necessary to mate solid red and even roan with each other. If a white animal were used, it would be necessary to guard against the possible introduction of spottedness. Eventually a race could be bred true for the solid colors, though there would, for many generations, be a tendency for spotted animals

to appear. It would, on the other hand, be much easier to breed a race of spotted animals by simply mating roans amongst themselves.[1]

Inheritance of Spotting in Holsteins.—In a study of the mode of inheritance of degree of spotting in Holsteins it was found that the correlation between spotting on the two sides of the body was 0.971 ± 0.002. Of 142 cows studied, the range of spotting was from 1 to 92 per cent (or 10 to 925 units of black) with a mean grade of 43 per cent (or 433 units of black). Table LXII shows the mean grades of offspring of the light, medium, and dark bulls in units of black.

TABLE LXII.—DEGREES OF BLACK SPOTTING IN HOLSTEINS (*From Dunn, Schneider and Webb*)

Spotting of sire	Light	Medium	Dark
Average grade of bull	50	350	900
Average grade of cows	392	549	353
Average grade of parents	220	449	623
Average grade of offspring	201	430	638

The average result of crossing animals of different grades is the production of offspring whose average grade is intermediate between those of the parents. This is purely a statement of average facts and not an explanation of the inheritance.

Table LXIII shows the behavior of spotting in different types of matings:

TABLE LXIII.—RESULTS OF CROSSES AMONG HOLSTEIN CATTLE OF VARIOUS GRADES OF SPOTTING (*From Dunn, Schneider and Webb*)

Parents	Offspring			
	Light 0–249	Medium 250–699	Dark 700–949	Mean-grade offspring
Light × light	13	2	..	125.00 ± 81.68
Light × dark	1	7	..	431.25 ± 31.24
Light × dark	3	12	6	555.95 ± 33.85
Medium × medium	6	13	2	457.86 ± 32.38
Medium × light	20	7	..	175.00 ± 15.77
Medium × light	3	5	2	370.00 ± 50.98
Medium × dark	3	7	14	677.09 ± 34.21
Medium × dark	2	10	6	566.67 ± 37.12
Dark × dark	..	1	4	795.00 ± 56.11
Total	51	64	34	149

[1] SMITH, A. D. B., Shorthorn colors, *Jour. Heredity*, **16** (3): 78, 81, 82, 1925.

The preliminary evidence is sufficient to indicate that:

1. Differences in amounts of spotting in Holstein cattle are inherited, and amenable to selection even when this is practiced on the male side only, as in the present case.

2. That the darker grades are probably partially dominant over the lighter grades.

3. That segregation of factors determining the grosser difference in spotting occurs.

4. That some degree of blending occurs, due possibly to minor modifying factors whose expression, together with that of the major factor or factors, may be obscured by non-genetic variation at present not measured.

5. Because of the extreme rarity of proved cases of identical twinning in cattle it will probably not be possible to measure the amount of this non-genetic variability by the comparison of the spotting patterns of monosexual twins.

The present data cannot be used for measuring the number of the quantitive effects of the factors involved, since in the absence of knowledge concerning the genotypes of the animals used the proportions of offspring of various types can have little significance. There is every indication, however, that an exact interpretation can be arrived at through the collection and study of more data.[1]

Albinism in Cattle.—There is a record[2] of a herd of albino cattle which arose from the production of an albino bull and heifer in a grade Holstein herd in Minnesota. The sire of these individuals, a purebred Holstein, produced eighteen normal black-and-white calves in this herd during the same year. From memory, the owner stated that the albino bull bred to about twenty of the grade cows produced all albino offspring. This, as Detlefsen points out, is a peculiar condition, because it is logical to assume that the original albinism which cropped out was due to the mating of animals carrying the factor for albinism as a recessive, and yet this albino bull acted in later breeding like a homozygous dominant. Albinos mated *inter se* are said to have produced only albinos, and from albino females mated to a Holstein bull three albinos and one normal Holstein. These albinos were extremely sensitive to light. Their milk production was not exceptional in any respect.

[1] Dunn, Schneider, and Webb, Spotting in cattle, *Jour. Heredity*, **14**: 236–240, 1923.

[2] Detlefsen, J. A., A herd of albino cattle, *Jour. Heredity*, **11** (8): 1920.

Other Data on Inheritance in Cattle.—It is reported[1] that purebred Dutch Belted cattle sometimes produce self-colored (black or red) calves, presumably being heterozygous for the belted pattern. A bull heterozygous for belt but homozygous for black mated to sixty pied heifers (mostly black, six red, one white face) produced twenty-seven belted (often with white hind feet), twenty-five self (sometimes with a small white spot), and three pied. By assuming a factor for belt *B*, another factor for self-color *S*, and "a repulsion between *B* and *S* in accordance with the reduplication series, 1:7:7:1," the observed results will be very closely approximated, this in contrast to Wright's view that pied (including belt) is due to two sorts of factors, those which determine a certain general level of some essential for pigment production and those which affect the course of development so as to bring out particular lines of weakness in which the pattern of white shall appear if the level is low enough.

Hooper reports[2] that crossing a Holstein bull and Jersey cows (some high grades) gave three solid-black calves, one black with white legs, and two black and white. He says "Jersey color is entirely recessive to Holstein color, as the faun did not appear." On the basis of Wright's analysis, the Jersey might be *vv EE DD*, and the Holstein *Vv Ee dd*, so that it would be possible to get *vv EE Dd*, a black offspring, provided the two *E* factors did not permit the *D* (dilution) to develop, or *Vv EE Dd* a pied (black and white).

Lush reports[3] a notch in the under side of the ear found in Jersey cattle at Texas A. & M. College to be due to a single dominant factor independent of sex. No factors of economic importance are as yet known to be linked with the factor for notch.

Lush reports[4] a peculiarity in the ears of Brahma cattle in Texas to be in all probability due to a single dominant Mendelian factor which is not sex linked and not associated so far as known with economically important features. The evidence, secured from cattle owners, is strictly verbal and from memory.

[1] KUIPER, K., Color inheritance in cattle, *Jour. Heredity*, **12** (3): 107, 1921.

[2] HOOPER, J. J., Color of crossbred calves, *Jour. Heredity*, **12** (10): 480, 1921.

[3] LUSH, J. L., A notch in ears of Jersey cattle, *Jour. Heredity*, **13** (1): 8, 1922.

[4] LUSH, J. L., Double ears in Brahma cattle, *Jour. Heredity*, **15** (2): 93, 1924.

The peculiarity is commonly called "double ears" but is really merely a thin, flat piece of cartilage parallel to the main axis of the ear and projecting out of the back surface of the ear very much as the dorsal fin of a fish projects from its back.

An investigation on Holstein milk yield is reported by Marshall,[1] in which the milk yield, fat yield, and fat percentage of 665 cows were correlated with those of their paternal and maternal granddams. There were no significant correlations found in either group, but the number of cases in which the resemblance was closest on the maternal side outnumbered those closest on the sire's side. This is opposed to the idea that "the males of dairy breeds, generally, are prepotent in the transmission of the characteristics of the females of their race."

Kulhman reports[2] the the F_1 generation cross between Angus and Jersey results in offspring which very closely resemble the Angus, being black or dun in color, polled, and rather beefy in conformation. They also show a high yield of milk and butterfat, ranging almost as high as their Jersey dams. In the F_2 generation there is the expected variation in conformation and color due to segregation and recombination of the characters of the original parents. The author lists the following characteristics as appearing in the F_2:

Black-polled "Angus" type.
Black horned.
Black with indication of fawn, "Jersey" type.
Black and white, horned.
Orange fawn with light muzzle and polled.
Brindled fawn with dark muzzle.
Black with gray hairs in face.

The aim here was to develop a strain of cattle suited to the rather rigorous conditions of northern England and at the same time a strain that would be fairly efficient and high milk producers. The writer has been unable to obtain information relative to the progress of this crossbreeding experiment.

Crosses between zebu and native Italian cattle, made at the zoötechnical institute of Perugia, are discussed by Director Carlo Pucci in *L'Agricoltura Coloniale*, No. 10, 1914. The results convince him that: (1) in all the first-generation progeny the zebu skeleton, dewlap,

[1] MARSHALL, F. R., Holstein milk yield, *Jour. Heredity*, **5** (10): 437–439, 1914.

[2] KUHLMAN, A. H., Jersey-Angus cattle, *Jour. Heredity*, **6** (2): 72, 1915.

ear, and musculature seem to be dominant; (2) the skin color and size of horns of the zebu seem to be recessive; (3) in general, all the progeny show great activity and endurance; (4) they have a very valuable predisposition to lay on weight; (5) they have a very high resistance to the foot-and-mouth disease.[1]

Cole[2] reports a case of a Holstein bull with defective (small, irregular shape, some wanting) teeth as producing in two successive years five calves with deficient coats; three of these calves are known to have had defective dentition. The mouths of the other calves were not examined. While the calves were young they had noticeably short hair on the head and neck. None of the animals were retained for genetic investigation.

Maine Station Crossbreeding Experiments.—The Maine Agricultural Experiment Station, realizing the need for data on hereditary transmission of characteristics in cattle, began a crossbreeding experiment in 1913 under the direction of Dr. Raymond Pearl, which has been continued since the war by Prof. J. W. Gowen. They started with Jerseys, Holsteins, and Aberdeen-Angus, thus giving them the various contrasted characters as listed by Gowen in Table LXIV.

TABLE LXIV.—CONTRASTING CHARACTERS OF THE PARENTAL BREEDS OF THE CROSSBRED HERD

Character	Jersey	Holstein	Aberdeen-Angus
Body color	Fawn or dun	Black	Black
White markings	Often absent	Present	Often absent
Switch color	Black or white	Black or white	Black
Muzzle pigment	Black	Black or white	Black
Tongue pigment	Black	Black or white	Black
Horns	Horns	Horns	Polled
Conformation	Dairy	Dairy	Beef
Milk quantity	Medium	Large	Low
Milk quality	High	Low	High

Some of the characteristics, such as coat color, tongue color, etc., are not of economic importance, but "the intimate association which exists between the hereditary units" renders it desirable to secure data on the inheritance of all the contrasting

[1] Anonymous, Crosses with zebra cattle, *Jour. Heredity*, **6** (3): 144, 1915.

[2] COLE, L. J., A defect of hair and teeth in cattle, probably hereditary, *Jour. Heredity*, **10** (7): 303–306, 1919.

characters which can be studied, regardless of their nature. "It is the purpose of this preliminary paper on the first-generation hybrids to lay the foundation for acquiring exact knowledge of such things as milk and beef production." The following are excerpts from preliminary papers on the subject by Gowen.[1]

Black body color is dominant to all other colors, red, brown, and fawn. Two interesting cases of segregation occur. The deep-orange-coated bull and the dark fawn heifer are shown to come from matings of black F_1 parents. These cases are too few to base any definite conclusions as to the number of factors in coat-color inheritance, but what they do indicate is that there is a particular inheritance and not a blending one . . .

The F_2 generation of our crosses contains two very interesting animals, as above mentioned: One, a deep-orange bull, was the result of a back-crossed black F_1 bull carrying the Guernsey color onto a Guernsey. The other was produced by a back cross of a black F_1 bull, Holstein-Friesian Jersey, onto a dark Jersey. The coat of this heifer was very dark. The appearance of the dark-fawn and deep-orange offspring from black F_1 parents indicates that segregation of the parental coat colors does occur. The deep-orange bull is of especial interest, since he shows the segregation of the Guernsey coat with the color modified. This deepening of the shade of the coat seems to be confirmatory evidence for the hypothesis advanced by Wright that the coat color of Guernsey cattle differs from the other dun-colored breeds by a recessive dilution factor for this fawn. The proof for this factor being recessive comes in the fact that the F_1 cross was a back cross of a black Guernsey F_1 bull on a Guernsey cow. Furthermore, this factor, from the nature of the cross, cannot be sex-linked as in the case of Wentworth's explanation of the dark shade of brown in the coat of the male Ayrshire.

The case of the almost identical appearance of the dark dun F_2 heifer and her Jersey parent agrees well with the findings of Kuhlman for Jersey $\times$ Aberdeen-Angus crosses. These cases support the conclusion that in the Jerseys any such dilution factor as that in the Guernsey is not normally present . . .

Analysis by the method of individual white spots has shown a marked difference in the inheritance of such spots throughout the animal's coat. This is perhaps as far as the writer should go, and is the only conclusion it is intended to emphasize; but realizing that there are exceptions not yet accounted for, it may be said that white spotting in the inquinal region is, broadly speaking, dominant. The spots of the rest of the pie-

[1] GOWEN, J. W., Studies in inheritance of certain characters of crosses between dairy and beef breeds of cattle, *Jour. Agr. Research*, **15** (1): 1–58, 1918.

bald pattern are, individually considered, recessive. These enumerated individually according to the region in which they occur are: (1) white on the face (star, star snip, or blaze), (2) white on the throat, (3) white as a band across the shoulders, (4) a white area on the rump at the base of the tail set, (5) white on the flanks as irregular spots, (6) white on the tail above the switch, and (7) the white stockings on the four feet.

The bearing of this difference in inherited behavior on the general problem is at once evident. If the red-coated Shorthorns should carry one of these recessive white spots, we should expect a small proportion of cattle produced from the random mating of such an animal in the Shorthorn population which would be white spotted. In point of fact, this is what has actually been obtained. The reverse is also true that, if these dominant white are mated together, we should expect that a heterozygous mating would now and then take place, giving a red. The evidence brought forward offers a straightforward, clear explanation of the anomolous behavior of the Shorthorn coat . . .

The pigmented muzzle is dominant to the non-pigmented one . . .

Pigmented is dominant to unpigmented tongue . . .

We have two exceptional cases for polledness which demand a supplementary hypothesis to explain their apperance . . . These data make it probable that sex has some influence on the horned condition . . .

The dairy and beef qualities are seen to be blended to a considerable extent in the F_1 offspring. Even with this blending, however, dominance and recessiveness may be discerned in the crosses. The beef qualities are, in general, quite pronounced in the head and forequarters of these hybrids. The dairy qualities seem to predominate in the barrel and hindquarters.[1]

In the light of these all too meager data, the results of this paper would seem to be supported by those of the other investigations on this subject. Such being the case, the conclusion seems sound that the inheritance of milk yield appears to show a partial dominance of the high milk yield to the low milk yield.[2]

The inheritance of butter-fat percentage has occupied a prominent place in the discussions of breeding operations by practical dairymen. These men have held the following views as to the mode of this inheritance. The first has claimed that the tendency for high or low butter-fat percentage is transmitted by the sire to his offspring; the second that the dam transmits the tendency for high or low butter-fat percentage to the offspring; and the third that both parents contribute to the butter-fat percentage transmission. The results of these experiments show that

[1] Gowen, J. W., Studies in inheritance, etc., *Jour. Agr. Research*, **15** (1): 1–58, 1918.

[2] Gowen, J. W., Inheritance in crosses, etc., *Jour. Heredity*, **11** (7): 300, 1920.

the third of these claims is correct. Such being the case, the dairyman who wishes his breeding operations to progress successfully will find it desirable to examine both sides of his animal's pedigrees carefully.[1]

Summary on Inheritance in Cattle.—Castle[2] lists the polled as being dominant to the horned condition. And the same author lists Dexter form (short legs) as a dominant to Kerry form (legs normal).

The foregoing data on inheritance in cattle are summarized in Table LXV. It is not presumed to be 100 per cent accurate.

TABLE LXV.—INHERITANCE IN CATTLE

DOMINANT	RECESSIVE
High milk yield[1]	Low milk yield
Low fat percentage[1]	High fat, percentage
Beef type in head and forequarters	Dairy type
Dairy type, in rear quarters	Beef type
Zebu, skeleton, dewlap	Native India cattle
Native India cattle:	Zebu
Skin color	
Size of horns	
Black	Red, dun, yellow, brown, fawn
White spotting, inguinal region	White spotting on face, throat, shoulders, rump, tail above switch, legs
Defective small teeth	Normal
Albino	Pigment
Ear notched	Ear normal
Ear double	Ear normal
Muzzle pigmented	Muzzle clear
Tongue pigmented	Tongue clear
Polled	Horned

[1] Not pure dominants.

Inheritance in Sheep.—Dr. Young[3] reports that Karakuls crossed on fine wools or medium wools produce a poor fleece which does not curl tightly nor have the desired luster. White Karakuls crossed on coarse wools produce a fleece which is both tightly curled and lustrous.

F. R. Marshall introduced Corriedale sheep into the United States from New Zealand. This breed oniginated in the late seventies from the crossing of Lincolns and English Leicesters on

[1] GOWEN, J. W., Inheritance in crosses of dairy and beef breeds of cattle, *Jour. Heredity*, **11** (8): 376, 1920.

[2] CASTLE, W. E., Genetics and eugenics, Harvard University Press, p. 131, 1920.

[3] YOUNG, C. C., *Jour. Heredity*, **5** (4): 170, 1914.

Merinos. It combines wool and mutton production and breeds fairly true as a blend of two parents with very little segregation.

E. G. Ritzman[1] reports matings of short-eared sheep (7 centimeters) with long-eared sheep (10 centimeters) as giving an equality of short- and long-eared sheep. Mating two short-eared sheep produced an earless sheep. He concludes that earless is pure dominant for short *SS*, short ears is heterozygous *Ss*, and long ear is pure recessive *ss*.

Davenport found black wool recessive to white in sheep. Black crossed on black always giving black, while white crossed on white sometimes gives black as a recessive. Duck[2] however, reports that when Karakul (black at birth) is crossed on white wool, black behaves as a dominant. He also says that the curl, density, and luster of wool of Karakuls are dominants to straight, long, and dull wool. Some Karakuls might conceivably be heterozygous for both the color and fur factors.

C. Wriedt[3] of Norway reports that Gromet pattern, consisting of "black marks over the eyes, black ears with grey margins, and occasionally dark stripes on the neck and breast," is a simple recessive to the factor both for white face and for black face.

Wood has studied crosses between Dorset and Suffolk sheep. The latter are hornless in both sexes. The F_1 of this cross consists of horned rams and hornless ewes. The F_2 consists of horned and hornless individuals in both sexes in the approximate ratio: 3 horned ♂ : 1 hornless ♂ : 1 horned ♀ : 3 hornless ♀. Bateson and Punnet assume that the horned breeds are of the constitution *HH XX*, female, and *HH XY*, male; and the hornless, *hh XX*, female, and *hh XY*, male. The F_1 then consists of *Hh XX*, hornless females, and *Hh XY*, horned males. Here they make the assumption that one dose of the factor *H* results in the production of horns in the male on account of the sex relations, but in the female two doses are necessary for the development of horns. This hypothesis does not account for those breeds which are horned in the male and hornless in the female, but it is not absolutely necessary that it should.[4]

Studies on Inheritance in Sheep.—Dr. Alexander Graham Bell established a flock of sheep at Berin Bhreagh, N. S., with the

[1] Ritzman, E. G., Breeding earless sheep, *Jour. Heredity*, **11**: 239, 1920.

[2] Duck, R. W., *Jour. Heredity*, **12** (9): 410, 1921.

[3] Wriedt, C., Jr., The "Gromet" patter in sheep, *Jour. Heredity*, **15** (3): 125, 1924.

[4] Babcock and Clausen, Genetics in relation to agriculture, McGraw-Hill Book Company, Inc., p. 549, 1918.

idea of developing a strain of sheep that would possess more than the ordinary number of nipples (two) believing that a tendency to produce twins or triplets would result from such selection. Castle has analyzed the records of this flock and drawn among others the following conclusions:

1. The character supernumerary nipples, by which is meant the possession of more than one pair, is strongly inherited.

Four-nippled sheep were present from beginning. No six-nippled sheep arose from the four-nippled. Six-nippled sheep were purchased outside. Average nipples in lambs 1890, 2.27; 1892, 3.14; 1896, 4.18; 1909, 5.00; 1913, 5.40; not surpassed and only equaled once in next 10 years.

2. The particular grade of multinippled condition borne by the parents is, as a rule, inherited by the offspring. Mating two-nippled Dorset ewes with six-nippled rams gave lambs with an average of 3.0 nipples. Mating four-nippled Dorset ewes with six-nippled rams gave lambs with an average of 3.73 nipples.

On the whole, it appears that the normal low-nipple number has a tendency to dominate in crosses, but that a first-generation hybrid somatically high in nipple number is also genetically high, and that the progeny of such an individual may even transcend the usual range of nipple number in the uncrossed races. Thus by crossing multinippled families in different breeds of sheep a race of still higher grade in nipple number might be secured. What is true of nipple number might conceivably also be true of functional performance of the supernumerary nipples.

3. The occurrence of twinning is much more erratic than that of multiple nipples and less clearly due to heredity . . . In fact, the hereditary element in twinning is probably very small, while that of environment is large. Throughout the experiment preference was given to parents born as twins, and in the years 1897 to 1902 no rams were used except those born as twins. Despite the selection for twinning, the frequency of twinning in the flock did not increase prior to 1914. . . . In Mrs. Bell's flock, mothers born in multiple births are a little more likely to produce multiple births than mothers born as singles, but the difference is not great. In Davidson's flock the relation is reversed, mothers born as singles producing more twins than mothers born as twins. But here again the difference is small and of doubtful significance.

Dr. Bell observed "that breeding in October produces more twins than breeding in November or December." Thus nutrition

is probably of greater importance than inheritance in producing twins, as the widespread practice of "flushing" would indicate. "It is probable that the only genetic factors concerned in twinning in sheep are those which affect the general vigor of the mother, causing multiple rather than single ovulations."

> There is no necessary relation between nipple number and twinning . . . Nipple number rises in consequence of selection, but twinning does not, though environmental influences may send it mounting upward regardless of ancestry. This agrees with the finding of Parker and Bullard for swine. They studied the relation between size of litter among unborn pigs, and number of mammæ of the mother and found no correlation.[1]

The records, in general, substantiate the fact that black coat color is a simple recessive to white.

Color Inheritance in Swine.—One of the early references to inheritance in swine was the paper of Smith in 1913. From a number of matings of Yorkshire × Berkshires, Berkshires × Yorkshire, Yorkshire × Poland China, and Poland China × Yorkshire which furnished the F_1 generation and these various crossbreds the F_2 he concludes:

> These results show, in the first place, complete dominance of the Yorkshire white over the Berkshire or Poland China black in the F_1 or first hybrid generation;
>
> Secondly, they show a general tendency for the original parent colors to be expressed separately, and in the proportion of 3 dominants: 1 recessive, in the individuals of the F_2 or second hybrid generation; and
>
> Thirdly, in nearly all cases the recessive black of the F_2 generation carried more white than the original black parents. This suggests the requirement of a number of germinal factors for each color rather than a single factor. Although the factors may behave as a unit or single factor when mated with individuals carrying like factors, when crossed, the unity is destroyed and independent behavior on the part of some of the factors is the possible result.[2]

Fröhllich[3] gives the following summary of coat color inheritance in swine after reviewing the observations in the United States and Germany.

[1] Castle, W. E., The genetics of multinippled sheep, *Jour. Heredity*, **15** (2): 79–80, 81, 1924.

[2] Smith, W. W., Color inheritance in swine, *Amer. Breeders' Mag.*, **4**: 113, 1913.

[3] Fröhllich, Gustav, Color inheritance of pigs, *Jour. Heredity*, **5** (2): 92, 1914.

It appears that in the first filial generation of crosses the following are dominant:

I. White of Improved German Swine (Edelschwein) over:
  White and black of Hanoverians.
  Black of Berkshires.
  Grayish black of European wild pigs.
  Grayish black of Cornwalls.
  Red of Tamworths.
  Black of Caucasian wild pigs.
II. Grayish black of European wild pigs over:
  Red of Tamworth.
III. Black and white of Hampshires over:
  Red of Tamworth.

McLean has observed and discussed[1] the Sapphire hog. This so-called breed of swine was originated by crossing Yorkshires medium and large, Hampshires, Berkshires, Essex and Chester Whites, and possibly some Duroc Jersey. The blue color is due to an admixture of black and white hairs over the body and varies in shade. The writer visited this farm in 1918 and, while many blue hogs were to be seen (as well as countless other combinations of colors), the result of selecting primarily for color, namely, poor type, was also quite evident. The genetics of the blue hog is not very well understood.

In 1917 Severson reports a case of a mating of Duroc Jersey boar on a Berkshire sow, producing a litter of seven pigs, six of which were red with black spots and one black with white spots. The latter sow, designated I in the table below, and a red-and-black litter mate, designated II below, were mated to a Berkshire boar with the indicated result.

TABLE LXVI.—RESULTS OF MATING (*Severson*)

Breeding			Color of offspring		
Boar	Sow	Red and black	Black and white	Red, white, and black	Yellow and black
Duroc Jersey 58875	Berkshire 199330	6	1		
Berkshire 193411	Crossbred No. 1	1	5	2	1
Berkshire 193411	Crossbred No. II	2	4	4	

[1] MCLEAN, J. A., The sapphire pig, *Jour. Heredity*, **5** (7): 301, 1914.

These results are discussed later by Wright.

Severson makes the following observation on color in other crosses.

My observations with reference to the color shown in the crossing of the various breeds in the F_1 generation are as follows:

1. Berkshire × Tamworth:
   Red (darker than Duroc Jersey) with black spots.
2. Berkshire × Duroc Jersey:
   Red (varying Shades) with black spots.
   Black (rare) with white spots.
3. Berkshire × Yorkshire:
   White (solid).
   White with black spots (rare).
4. Yorkshire × Tamwhorth:
   White (solid) with reddish tint.
5. Yorkshire × Duroc Jersey:
   White (solid) with reddish tint.
6. Berkshire × Chester White:
   White (solid).
   White with spotted black (high proportion).

These observations do not agree with the general opinion and statements that the self-white of the Yorkshire is completely dominant over the red of the Tamworth and Duroc Jersey.[1]

Kansas Experiment Studies on Inheritance in Swine.—Lush[2] reports the result of 4 years experiments on inheritance in swine at the Kansas Experiment Station. The following is a digest of his report.

Litter Size.—Wild litter size (four) apparently dominant to larger litters.

Set of Ears.—Erect ear dominant to lop ear by three principal and perhaps some modifying factors.

Shape of Face.—Long, narrow straight (wild) apparently dominant over Tamworth type.

Long, narrow straight (wild) dominant over Berkshire type.

Shape of Face.—Fairly long, narrow, straight (Tamworth) dominant over Berkshire type. Short dished face (Berkshire) partially dominant over moderate length of dish of Duroc.

Colors. White.—(This includes a summary of previous work in color inheritance.) Self-white dominant over all other colors (one

[1] Severson, B. O., Color inheritance in swine, *Jour. Heredity*, **8**: 381, 1917.

[2] Lush, J. L., Inheritance in swine, *Jour. Heredity*, **12** (2): 9, 1921.

factor). White belt usually dominant (two factors). Six white points are extremely diluted red. No albinism in swine.

Black.—Self-black (English large black) dominant to Tamworth red; Hampshire black dominant to Duroc red (one factor); Berkshire, Poland China black when crossed with red breaks up into black spots on lighter background of red, sandy, or white. Single factor extended by modifying factors to cover all of body except six white points.

Red.—Two kinds of self-reds. Tamworth red nearly dominant over Berkshire black—strong restriction factors for black in Tamworth.

Duroc red when crossed with black allows more black spots to appear (as masked out at birth black contrasted with absence of black gives perfect 3 : 1 ratio in F_2 and a close approximation to 1:1 in the backcross).

Duroc has two factors, absent in the Berkshires, both necessary for production of red.

Roaning.—"Appears quite frequently among the descendants of self-whites by self-reds, or of self-whites by belted blacks. Often it is not apparent at birth but develops later."

Immature Striping and Adult Agouti of the Wild Hog.—This pattern is dominant over all other colors except self-white and the white belt, but the dominance is not always complete.

Differences in Growth.—Berkshires × Duroc Jersey cross gave F_1 individuals with a distinctly lower coefficient of variability than was secured from F_2, therefore "some of the factors which have the power to stimulate growth are not identical in the Duroc Jersey and the Berkshire breeds and there is some degree of homozygosity for these growth stimulating factors within the limits of each breed." Four individuals of an F_2 litter fed and handled identically and none of which had ever been noticeably ill averaged in weight at eleven months 293, 221, 170, and 90 pounds.

Crew's Analysis of Color Inheritance in Swine.—Crew[1] reports a genetic analysis to explain the exceptional production of black-and-white offspring from a mating of a large white boar on a large black sow; such mating usually gives blue and whites or blue roans, favored alike in both cattle and swine as an early-maturing profitable meat animal. The author reports a recent case of a purebred, large white boar mated with seven large black sows producing litters approximately one-half of which were blue and white and the other half were black and white.

[1] Crew, F. A. E., Blue and white color in swine, *Jour. Heredity*, **15** (9): 395, 1924.

The facts in so far as they are known can be accommodated by the following tentative scheme:

B = the factor for black; b = that for white; P = that for the particolored condition, restriction of color—probably multiple factors are concerned; D = a dilution factor turning black into blue. The following chart shows the percentage of offspring produced by the various matings:

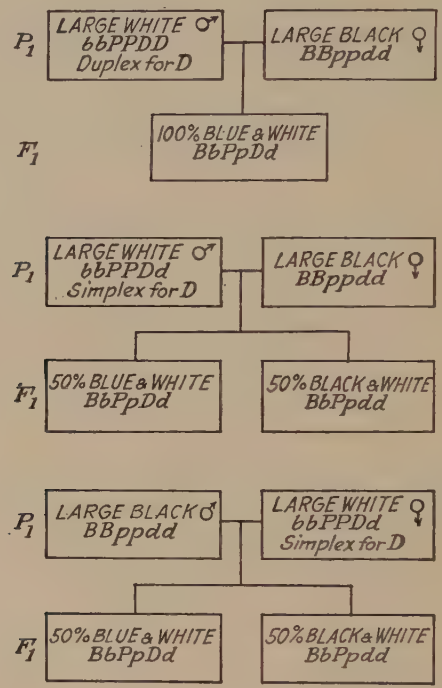


Fig. 113.—Diagram showing results of matings of Large White Swine of different genotypes with Large Black Swine and the production of the blue and white pig or blue roan. (*From Crew.*)

The production of 100 per cent blue and whites is dependent upon the "elimination of the individual simplex for the dilution factor." Breeders generally suppose the black and whites to be inferior to the blue and whites, though this has not been tested experimentally.

Wright's Analysis of Swine Color Inheritance.—According to Wright's formula, the following is the classification of colors in swine.[1]

[1] Wright, S., Color inheritance in mammals, *Jour. Heredity*, **9** (1): 33–38, 1918.

SOLID BLACK HOG—vdE_H

$1a_1$	
$1a_2$ V, v	V—white belt of Hampshire. Unit factor not certain.
$1a_3$	
$1b$ D, d	$E_y d$—white to roan, $E_y d$—sandy to red.
$2a_1$	Agouti of wild *vs.* black of Hampshire?
$2a_2$ E_Y, E_B, E_H	E_B—Black spots on red ground (carried by selection nearly to solid black in Berkshires and Poland Chinas, to solid red in Duroc-Jersey and Tamworth.
	E_Y—solid red (present associated with D in solid white Yorkshire and Chesters).
	$E_Y E_B$ and E_H have not been proved to be triple allelmorphs. Two independent sets of factors may be involved.
$2a_3$	Black of Hampshire *vs.* agouti of wild? (See $2a_1$.)
$2b$	

The wild hog is of an agouti pattern. In present-day breeds there are many colors and combinations, including self-whites, red, and blacks as well as bicolors and tricolors. There are three types of white: (1) solid white (Yorkshire, Chester), (2) Hampshire type (belt), probably dependent on at least two factors, (3) irregularly spotted and roaning (red or blue).

Smith reports Yorkshire crossed on Berkshire or Poland China as giving whites in F_1 and half whites and half blacks when back crossed and an F_2 of twenty white to six splotched black. This indicates a unit factor different, though there are certain difficulties in the way of accepting Yorkshire as a pure dominant. Wright has pointed out the inadequacy of a three-factor allelomorph system to explain certain types of color behavior in Yorkshire, Tamworth, and Duroc crosses with the black breeds, black being practically absent in all such crosses and indicating that Yorkshire and Tamworth have similar restrictive factors. This, however, is disproved by the fact that Hampshire $\times$ Tamworth produces full extension of black, while Hampshire $\times$ Yorkshire gives full restriction (white).

Assuming Yorkshire to have a dominant unit restriction factor, Tamworth a recessive restriction factor for extended black, Yorkshires a dominant unit dilution factor (white), and Tamworths a recessive unit dilution factor (red), Wright has constructed an independent extension and dilution series which explains the production of pure red offspring from Hampshire or Poland China boars on York-Tamworth sows as being due to the union in the hybrid sows of the dominant restriction factor of the Yorkshires with the recessive dilution factor of the Tamworth. The following diagram should make this clear:

Ey Ey DD (Yorkshire) *EbEb dd* (Tamworth)
EyD *Ebd*
Ey Eb Dd (hybrid white) E_H E_H *dd* (Hampshire black)
Eyd $E_H d$
EyE_H *dd* red offspring by Hampshire boar.

Thus restriction of Yorkshire and restriction of Tamworth show a segregating difference in their reaction to extended black. It has also been noted that extension of Hampshire and of Berkshire or Poland-China show differences which are increased by crosses with a given red. The difference between Berkshire or Poland-China and Tamworth or Duroc, on the other hand, tends to be reduced by crosses, and there seems to be no good evidence of segregation. Berkshire extension comes out of Yorkshire crosses with almost as much white as black, while Duroc restriction often comes out of Yorkshire crosses with black spots. Thus it is not impossible that Berkshire black and Duroc red may possess the same main factors for extension, but have become distinct in appearance through a process of selection of minor factors.

Turning to intensity, the evidence is clear that white of Yorkshire differs from red of Tamworth by at least one clear-cut dominant factor. There is difficulty, however, in attempting to classify the Berkshires, Poland-Chinas, and Hampshires with repect to this series. The fact that the first two ordinarily show only white in place of red would lead one to classify them with Yorkshire. The failure of reds to appear when these breeds are crossed twice with Yorkshires is further evidence in this direction. On the other hand, Berkshires and Poland-Chinas may show sandy splotches themselves and in crosses with Tamworths or Durocs produce black-and-red pigs in F_1 in marked contrast with the whites from Yorkshire crosses. Similar results were shown in the more complex crosses cited above.

Some evidence has recently been presented by Severson on crosses between Berkshire and Duroc-Jersey which bears on the genetic relations both as regards intensity of red and extension of black. The offspring of the cross were variable but all intermediate between the parents. Ten were red with varying amounts of black spotting, while two were predominately black, the parts which were not black being white in them. Two sows representing extreme types in F_1, a red with black spots and a black with white splotches, were backcrossed with a Berkshire boar. The same kinds of young were produced in both cases. There were reds with black spots, blacks with white splotches, and tri-colors. These classes graded into each other and there was no evidence for segregation of an outstanding unit factor either for extension of black or intensity of red. The indications are that both Berkshires and Durocs possess the same partial extension factor and the same intensity

factor. The genetic evidence suggests that both have been selected from a sandy-colored hog with black spots. From such a foundation (as far as color is concerned), Durocs (and Tamworths) have been selected for restriction and intensity, so producing solid-red breeds, while Berkshires (and Poland-Chinas) have been selected for extension and dilution, so producing black breeds with white points. Selection appears to have worked through minor factors, leaving the major factors essentially the same in all four breeds.

In Severson's crosses, extension of black appears to be associated with dilution of red. Whether this is merely accidental or because the paler parts of the coat are the last to be invaded by black or because there is a real physiological interrelation is not clear. Under the last head it is conceivable that competition between the processes of forming black-and-red pigment might lead to such a correlation.

The conclusions reached may be summarized in the scheme of factors given below. A system of three allelomorphs in the extension series is adopted for simplicity. There may equally well be two sets of independent factors as far as present evidence goes. The formulas which must be assigned to certain of the breeds are also given below.

Ey Ey	White to roan	Sandy to red
Ey Eb	White to roan	Sandy to red
Ey Eh	White to roan	Sandy to red
Eb Eh	White or roan + black spots	Sandy or red + black spots
Eb Eh	Black	Black
Eh Eh	Black	Black

Yorkshire (white), Chester (white) — *Ey Ey DD vv*

Tamworth (red), Doroc Jersey (red) — *Eb Eb dd vv* + minor factors for intensity of red and restriction of black.

Berkshire (black-white), Poland-China (black-white) — *Eb Eb dd vv* minor factors for dilution of red and extension of black.

Hampshire (black-white) — *Eh Eh dd VV*

Essex (black) — *Eh Eh dd vv*

Wild boar (agouti) — *Eh Eh dd vv* + agouti factor or factors.

In concluding this summary, it is clear that color inheritance in hogs is a subject on which much is yet to be done. Nevertheless, the main facts seem to point quite definitely to three independent kinds of variations as responsible for most colors: First, black extension (no black—small black spots—black except for irregular splotches—solid black). Second, variations of intensity which determines whether the ground color shall be white, sandy, or red. A third independent kind of variation is clearly present in the white belted swine, in which there is a white which can appear on either a black or a red. Further investigation is needed in all three of these groups to determine whether the important

variations fall into series of multiple allelomorphs or are due to independent factors.[1]

Other Data on Inheritance in Swine.—Castle states that the "banded (longitudinal striped) character of both young and adult has apparently been lost in all domestic breeds, which are either self-black, red, or white or else black or red spotted with white, yet it occasionally reappears in crosses showing a probable dependence upon complementary factors still found separately in certain breeds (Severson)."[2] He also points out the fact that in the white variety the entire coat is colorless but the eye is colored.

The "mule-foot" condition, the two hoofs of each foot fused into one hoof, is a dominant unit character. The breed known as the mule-foot is sometimes erroneously claimed to be immune to cholera.

As will be noted, the foregoing knowledge of inheritance in swine is somewhat conflicting and meager and deals for the most part with superficial characters. The question of the inheritance of size, rate of growth, fertility, quality, and other matters of basic importance are yet to be studied.

Study of 3,540 litters of pigs is reported[3] by Edward N. Wentworth and C. E. Aubel in the *Journal of Agricultural Research* (Mar. 20, 1916). Previous studies had indicated that fecundity is to some extent an inherited character, although the degree of resemblances between parent and offspring in this respect is not large. Crossbreeding has given some reason to suspect that a number of distinct, inheritable factors influence fecundity; it is also certain, of course, that fecundity is influenced by numerous factors which have nothing to do with heredity. The analysis of data showed some evidence of the presence of three distinct hereditary factors, but further research will be required before any result can be announced with confidence. The study is obviously an important one, in view of the great value of high fecundity in domesticated animals.

Conclusion on Inheritance in Farm Animals.—A sufficient length of time has not elapsed for the accumulation of enough data on inheritance in farm animals for any broad generalizations. It is hopeful that the task has been attempted and a beginning

[1] Wright, S., Color inheritance in mammals, *Jour. Heredity*, **9**: 36, 37, 38, 1918.

[2] Castle, W. E., Genetics and eugenics, p. 177, 1924.

[3] Anonymous, Inheritance of fertility of swine, *Jour. Heredity*, **7** (5): 234, 1916.

made. It should be possible to derive a great deal of information about the problem of hereditary transmission of characters from the practice of experimental crossbreeding. In the early days of genetics many unfounded hopes were held out to the practical breeder that this new science would quickly solve all his difficulties and give him a short cut to success in the shape of formulas by which prize-winning and record-breaking animals might be created. Such a possibility never existed. Most animal characteristics are much more complicated genetically than are tall and dwarf peas. Perhaps most characteristics of animals are controlled not by one but by hundreds of factors. To have an idea as to how they are actually controlled is certainly worth while. Through analytical genetics it should be possible to determine to some extent the chromosomal make-up of the various breeds of animals and their best representatives and it seems reasonable to hope that such knowledge will expedite the production of greater numbers of more efficient animals.

APPENDIX C

PEDIGREE REGISTER ASSOCIATIONS[1]

The following compilation of pedigree registers maintained in the United States for purebred stock has been revised with much care, and is believed to be correct. All inquiries concerning rules of registration and pedigrees of animals of the various breeds should be directed to the secretaries.

Cattle Registers

American Aberdeen-Angus Breeders' Association, W. H. Tomhave, Stock Yards, Chicago, Secretary.

American Devon Cattle Club, W. J. Neal, Meredith, N. H., Secretary.

American Galloway Breeders' Association, R. W. Brown, Carrollton, Mo., Secretary.

American Guernsey Cattle Club, Karl B. Musser, Peterboro, N. H., Secretary.

American Hereford Cattle Breeders' Association, R. J. Kinzer, Kansas City, Mo., Secretary.

American Jersey Cattle Club, R. M. Gow, 324 West 23 St., New York, Secretary.

American Polled Hereford Breeders' Association, B. O. Gammon, Des Moines, Iowa, Secretary.

American Shorthorn Breeders' Association, P. K. Groves, Stock Yards, Chicago, Secretary.

Ayrshire Breeders' Association, C. T. Conklin, Brandon, Vt., Secretary.

Breeders' Association of French-Canadian Cattle of the United States, W. J. McMurdy, Binghamton, N. Y., Secretary.

Brown Swiss Cattle Breeders' Association, Ira Inman, Beloit, Wis., Secretary.

Dutch Belted Cattle Association of America, R. J. Leonard, Rockville, Conn., Secretary.

Holstein-Friesian Association of America, F. L. Houghton, Brattleboro, Vt., Secretary.

Milking Shorthorn Society, Roy A. Cook, Independence, Iowa, Secretary.

The American Polled Shorthorn Breeders' Association, J. L. Tormey, Record Building, U. S. Yards, Chicago, Secretary.

Red Polled Cattle Club of America, Harley A. Martin, Richland Center, Wis., Secretary.

[1] Courtesy of *The Breeders' Gazette.*

Horse Registers

American Association of Importers and Breeders of Belgian Draft Horses, J. D. Conner, Jr., Wabash, Ind., Secretary.

American Clydesdale Association, Miss Margaret Coridan, Stock Yards, Chicago, Secretary.

American Hackney Horse Society, Gurney C. Gue, Merrick, L. I., N. Y., Secretary.

American Saddle Horse Breeders' Association, Roger H. Lillard, Louisville, Ky., Secretary.

American Shetland Pony Club, Miss Julia M. Wade, Lafayette, Ind., Secretary.

American Shire Horse Breeders' Association, W. G. Lynch, Tonica, Ill., Secretary.

American Jockey Club (thoroughbreds), Andrew Herkert, 66 West 40 St., New York City, Registrar.

American Suffolk Horse Association, R. P. Stericker, 72 West Adams St., Chicago, Ill., Secretary.

American Trotting Register Co., Frank E. Best, 137 South Ashland Blvd., Chicago, Secretary.

Arabian Horse Club of America, Elliott S. Humphrey, Box 184, Milan, N. H., Secretary.

Cleveland Bay Society of America, R. P. Stericker, 72 West Adams St., Chicago, Ill., Secretary.

French Coach Horse Society of America, Duncan E. Willett, Oak Park, Ill., Secretary.

German, Hanoverian and Oldenburg Coach Horse Breeders' Association, J. Crouch, Lafayette, Ind., Secretary.

National French Draft Horse Association, C. E. Stubbs, Fairfield, Iowa, Secretary.

Percheron Society of America, Ellis McFarland, Stock Yards, Chicago, Secretary.

Standard Jack and Jennet Registry of America, Inc., William E. Morton, Scarritt Building, Kansas City, Mo., Secretary.

The Morgan Horse Club, C. C. Stillman, 3 East 44 St., New York City, Secretary.

Welsh Pony and Cob Society, Miss Julia M. Wade, Lafayette, Ind., Secretary.

Sheep and Goat Registers

American Angora Goat Breeders' Association, G. E. De Groff, Sabinal, Tex., Secretary.

American Black-Faced Highland Sheep Association, F. R. Sanders, Mesa, Ariz., Secretary.

American Cheviot Sheep Society, G. W. Lough, Hartwick, N. Y., Secretary.

American Cotswold Registry Association, F. W. Harding, Waukesha, Wis., Secretary.

American and Delaine Merino Record Association, Gowdy Williamson, Xenia, Ohio, Secretary.

American Hampshire Sheep Association, C. A. Tyler, 36 Woodland Ave., Detroit, Mich.

American Leicester Breeders' Association, A. J. Temple, Cameron, Ill., Secretary.

American Milch Goat Record Association, Will L. Te Walt, Vincennes, Ind., Secretary.

American Oxford Down Association, W. A. Shafer, Hamilton, Ohio, Secretary.

American Rambouillet Sheep-Breeders' Association, Dwight Lincoln, Marysville, Ohio, Secretary.

American Romney Sheep-Breeders' Association, Mark Havenhill, 703 Rose St., Lexington, Ky., Secretary.

American Shropshire Registry Association, Miss Julia M. Wade, Lafayette, Ind., Secretary.

American Southdown Breeders' Association, William M. Henning, Pennsylvania State College, State College, Pa., Secretary.

American Suffolk Flock Registry Association, James Bowman, Guelph, Ont., Secretary.

American Tunis Sheep-Breeders' Association, G. C. Kreglow, De Graff, Ohio, Secretary.

Continental Dorset Club, J. R. Henderson, Hickory, Pa., Secretary.

Dickinson Record Co., Mrs. Beulah Miller, New Berlin, Ohio, Secretary.

Improved Black-Top Delaine Merino Sheep Breeders' Association, O. M. Robertson, Eaton Rapids, Mich., Secretary.

National Lincoln Sheep-Breeders' Association, D. T. Knight, Marlette, Mich., Secretary.

National Merino Sheep Register Association, R. O. Logan, Montgomery, Mich., Secretary.

Persian Sheep Breeders' Association, C. E. Bailey, San José, Cal., Secretary.

Standard Delaine Merino Sheep Breeders' Association, Robert Lawrence, Chelsea, Mich., Secretary.

SWINE REGISTERS

American Berkshire Association, E. M. Christen, Springfield, Ill., Secretary.

American Duroc-Jersey Swine-Breeder's Association, R. J. Evans, Stock Yards, Chicago, Secretary.

American Hampshire Swine Record Association, L. T. Bunn, Peroia, Ill., Secretary.

American Large Black Pig Society, J. F. Cook, Lexington, Ky., Secretary.

American Poland-China Record Co., George W. Davies, Transportation Building, Chicago, Secretary.

American Tamworth Swine Association, W. T. Barr, Ames, Iowa, Secretary.

American Yorkshire Club, H. G. Krum, 139 Capitol Ave., St. Paul, Minn., Secretary.

Cheshire Swine Breeders' Association, E. S. Hill, Freeville, N. Y., Secretary.

Chester White Record Association, F. F. Moore, Rochester, Ind., Secretary.

Improved Small Yorkshire Club of America, F. B. Steward, Espyville, Pa., Secretary.

National Chester White Record Association, Thomas Sharpless, West Chester, Pa., Secretary.

National Duroc Record Association, J. R. Pfander, Peoria, Ill., Secretary.

National Mulefoot Hog Record Association, G. C. Kreglow, De Graff, Ohio, Secretary.

National Poland-China Record Association, A. M. Brown, Winchester, Ind., Secretary.

National Spotted Poland-China Record Association, Fred L. Obenchain, 460 Century Building., Indianapolis, Ind., Secretary.

O. I. C. Swine Breeders' Association, O. C. Vernon, Goshen, Ind., Secretary.

Standard Poland-China Record Co., Frank L. Garrett, Maryville, Mo., Secretary.

United States Small Yorkshire Association, D. T. Bascom, California, via Montgomery, Mich., Secretary.

APPENDIX D

SUPPLEMENTARY REFERENCES

The following works will furnish excellent readings in the fields of genetics, reproductive physiology and animal breeding:

GENETICS

Author	Title	Publisher	Date
Babcock and Clausen	"Genetics in Relation to Agriculture"	The McGraw-Hill Book Company, Inc.	1918
Castle, W. E	"Genetics and Eugenics"	Harvard University Press	1924
Darwin, C	"The Origin of Species"	A. L. Burt Company	1859
East-Jones	"Inbreeding and Outbreeding"	J. B. Lippincott Company	1919
Jones, D. F	"Genetics"	John Wiley & Sons, Inc.	1925
Kammerer, P	"The Inheritance of Acquired Characteristics"	Boni & Liveright	1924
Morgan, T. H	"The Physical Basis of Heredity"	J. B. Lippincott Company	1919
Pearl, R	"Modes of Research in Genetics"	The Macmillan Company	1915
Sinnott and Dunn	"Principles of Genetics"	The McGraw-Hill Book Company, Inc.	1925
Shull, A. F	"Heredity"	The McGraw-Hill Book Company, Inc.	1925
Shull, A. F	"Principles of Animal Biology"	The McGraw-Hill Book Company, Inc.	1920
Walter, H	"Genetics"	The Macmillan Company	1919

REPRODUCTIVE PHYSIOLOGY

Bailey and Miller	"Text Book on Embryology"	William Wood and Company	1923
Bureau of Animal Industry.	"Diseases of Cattle"	Superintendent of Documents, Washington, D. C.	1923
Bureau of Animal Industry.	"Diseases of the Horse"	Superintendent of Documents, Washington, D. C.	1923
Marshall, F. H. A	"The Physiology of Farm Animals"	Cambridge University Press, England	1920
Marshall, F. H. A	"The Physiology of Reproduction"	Longmans, Green & Co.	1910
Sisson, S	"The Anatomy of the Domestic Animals"	W. B. Sanders and Co.	1914
Williams, W. A	"Diseases of the Genital Organs of Domestic Animals"	W. A. Williams Co.	1921

ART OF BREEDING

Author	Title	Publisher	Date
Armsby, H. P.	"The Nutrition of Farm Animals"	The Macmillan Company	1922
Crew, F. A. E.	"Animal Genetics"	Oliver and Boyd	1925
Davenport, E.	"Domesticated Animals and Plants"	Ginn and Company	1910
Davenport, E.	"Principles of Breeding"	Ginn and Company	1907
Finlay, G. F.	"Cattle Breeding"	Oliver and Boyd	1925
Gowen, J. W.	"Milk Secretion"	Williams & Wilkins	1924
Hill, C. L.	"Guernsey Breed"	*Kimball's Dairy Farmer*	1917
King, H. D.	"Studies on Inbreeding"	Wistar Institute	1919
Malin, D. F.	"Evolution of Breeds"	*Wallace Farmer*	1923
Marshall, F. R.	"Animal Breeding"	*Breeders' Gazette*	1911
McCollum, E. V.	"The Newer Knowledge of Nutrition"	The Macmillan Company	1922
Mumford, F. B.	"The Breeding of Animals"	The Macmillan Company	1917
Plumb, C. S.	"Types and Breeds of Farm Animals"	Ginn and Company	1920
Prescott and Prescott	"Holstein-Friesian Foundations"	*Holstein-Freisian World*	1923
Sanders, A. H.	"Shorthorn Cattle"	*Breeders' Gazette*	1900
Schoenleber and Dykstra	"Castration of Domestic Animals"	Orange Judd Co.	1915
Winters, L. M.	"Animal Breeding"	John Wiley & Sons, Inc.	1925

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